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THE INFLUENCE OF CLIMATE, SOIL, AND FERTILIZERS UPON QUALITY OF SOFT WINTER WHEAT

E. G. BAYFIELD[1]

INTRODUCTION

Growers of soft winter wheat throughout the three states of Ohio, Indiana, and Michigan in 1928 produced an abnormally small crop as a result of extremely heavy winter killing. Much of the wheat which came through the winter sufficiently well to be harvested consisted largely of varieties not strictly classed as "soft" winter wheat. Rather these were the more winter hardy introductions, such as Turkey Red and Kharkov, common to the hard red winter sections or varieties produced locally which possessed somewhat similar characteristics, such as Purkof and Michikof. The three states accordingly produced very little wheat of a type normal to the area and largely used by the millers producing cake, pastry, cracker, and similar flours. The crop harvested, however, very forcibly showed the millers the extent and quality of the winter wheats being introduced and grown on account of their superior winter hardiness, for they were unable to obtain their requirements of the superior soft winter wheats which the three states normally produced under their particular climatic and soil conditions.

As a result of this condition, a conference was held in Toledo on April 3, 1929, to evolve a satisfactory standardization program by which it was hoped to eliminate unsuitable and undesirable varieties in the three states. At this meeting millers, seed growers, representatives from the agricultural experiment stations, and others interested discussed the various phases of the question and agreed that maximum results would accrue from a cooperative attack on the problem. Pursuant to this object the Tri-State Soft Wheat Improvement Association was formed (45). A permanent committee composed of mill and agricultural experiment station representatives was organized and a carefully planned 5-year program inaugurated.

Under this program each of the three agricultural experiment stations undertook a certain definite phase of the problem for special investigation. The Ohio Station undertook the study of the effect of various environmental factors, principally soil and climate, upon the quality of soft winter wheat grown in the Tri-State Territory. As a result of these studies it was hoped that the three states could be zoned and that eventually the best adapted, high quality variety or varieties could be grown in each zone. The results of the first 5 years of this work are reported at this time.

STATUS OF WHEAT IN OHIO

Wheat is one of the most valuable crops produced in Ohio, and next to corn it is the most important grain crop. During the 50-year period from 1880 to 1929 the average annual Ohio production has exceeded 32,000,000 bushels. The crop occupied over 2,000,000 acres, or over 11 per cent of the total improved

[1]During the 5-year period commencing July 1, 1929, the author held the Fellowship supported by The National Milling Company, of Toledo, Ohio. The project was greatly assisted by the financial and laboratory assistance provided by this Company.

farm land in the State. The average yield equaled 15.3 bushels per acre. This low average yield fortunately has shown a tendency to increase gradually during the past 50 years.

Due to its geographical position, climate, and soil, Ohio produces most of its wheat from fall-sown land. A 1929 survey conducted by Clark and Quisenberry (19) showed only three-tenths of one per cent of the crop to be spring sown. Over 98 per cent of the crop was soft red winter wheat. At that time Ohio had the largest acreage of this class of wheat of any state in the Union, amounting to 14 per cent of the total United States soft red winter acreage. Ohio was shown to be growing about 2.5 per cent of the entire wheat acreage of the United States.

Ohio is the center of the most important soft red winter wheat producing area. Approximately 42 per cent of the United States wheat of this class is produced by Ohio and the adjacent states of Pennsylvania, West Virginia, Kentucky, Indiana, and Michigan. Table 1 gives the estimated acreages and classes of wheat grown in these states in 1929 (19). It may be observed that Indiana and Michigan sow a considerably larger percentage than Ohio of classes of wheat other than soft red winter.

TABLE 1.—Estimated Acreage and Percentage of Area Occupied by Different Classes of Wheat in 1929

State	Hard red spring		Durum		Hard red winter		Soft red winter		White		Total
	Acres	Pct.	Acres	Pct.	Acres	Pct.	Acres	Pct.	Acres	Pct.	Acres
Ohio	4,614	0.3	....	......	10,843	0.7	1,538,454	98.4	9,829	0.6	1,563,740
Indiana	1,357	0.1	....	......	154,202	10.1	1,374,734	89.6	2,738	0.2	1,533,031
Pennsylvania	920	0.1	....	......	698	0.1	979,469	99.2	6,013	0.6	987,100
Michigan	3,462	0.4	927	0.1	2,273	0.3	413,008	52.3	370,475	46.9	790,145
Kentucky	....	......	1,064	0.5	2,311	1.1	200,356	98.2	400	0.2	204,131
West Virginia	....	......	....	......	580	0.6	103,702	99.4	....	......	104,282

Recommended soft red winter wheats, such as Trumbull or Fulhio, when grown in Ohio produce crops which possess a quality desired by mills producing soft wheat flours. These flours are principally used in the manufacture of such products as soda crackers, cookies, cakes, and pastries. Hard red winter or hard spring wheats do not possess these desired qualities and are adapted primarily to bread production. However, these hard wheats when Ohio-grown are not particularly well adapted to bread flour production as they usually lack the desired strength. Despite this fact, a limited area, as indicated in Table 1, is annually planted to these varieties, particularly in sections possessing heavy soils where winter killing is exceptionally prevalent. Some of the hard red winter varieties are more cold resistant, although susceptible to soil heaving, than the recommended soft winter varieties.

Occasionally in Ohio the winter and spring weather is of such a nature that very serious injury occurs to the crop. Such "test" winters occurred in 1912, 1916, 1920, 1925, and 1928, when between 16 and 64 per cent of the wheat acreage was abandoned in the spring. The year 1928 was the worst on record during the past quarter century. In this year the total Ohio wheat crop was only about 9,331,000 bushels. Similar conditions prevailed in Indiana where 60 per cent of the acreage had to be abandoned. This severe winter was the direct cause of the present investigation.

METHOD OF ATTACKING PROBLEM

Climate and soil are the two most important environmental factors influencing wheat quality and these two factors are the principal ones under study. They will be dealt with individually when possible, although it may readily be recognized that it is impossible to deal with either one entirely alone under normal field conditions. The relative fertility of the soil has also been found to cause significant differences in the crop produced; hence, certain phases of fertilizer practices have been investigated in addition to the main problem.

To reduce the influence of climate to a minimum and thus to be enabled to study specifically the effect of different soils, a uniform series of varieties was grown upon several distinctly different soil types in close proximity to one another. Fulton County in northwestern Ohio was selected as a suitable location since it possesses a wide diversity of soils within its borders. For practical purposes the various wheat samples produced in this county, near Delta, Ohio, may be considered as having been produced under at least reasonably identical climatic conditions.

To study the effect of climate, the same set of varieties was grown upon a series of medium textured (neither heavy nor light) soils running roughly in a diagonal direction from northeastern to southwestern Ohio. To include the area of residual soils in the southeastern part of the State, two counties (Belmont and Meigs) in this area were also included. To broaden the range of environmental conditions still further, the Department of Agronomy of Purdue University, Lafayette, Indiana, and the Department of Farm Crops of the Michigan State College, East Lansing, Michigan, undertook to grow the same series of varieties at various locations in their respective states.

Since many cereal chemical tests are of an empirical nature, it was deemed advisable to have all samples tested in a uniform manner in one laboratory. The National Milling Company, of Toledo, Ohio, offered laboratory facilities for such test purposes. Accordingly, representative samples of suitable size from all plantings in the three states were sent to Toledo for milling and chemical determinations. The resulting data were all treated by the author in a uniform manner, and, as a result, direct comparisons may be made on samples originating in any of the three states concerned. Such would not be possible had the samples from each state been tested and evaluated in the respective state laboratories.

The project started in 1929 divides itself into two main divisions: (a) A general survey was made on the 1929 crop, as no special Tri-State plantings were made until the fall of that year. This survey gave considerable valuable information and prevented the loss of a year's time in beginning the project proper. The resulting data are presented under the heading "Preliminary Survey, 1929". (b) Beginning in 1930 the first of 4 years' results were obtained from the standard Tri-State sowings. The varieties included in this group will be referred to as the "Quality Series". In addition to this series, other samples grown under a variety of fertility conditions, principally at the Ohio Station, were tested during the 5-year period. The resulting data will be discussed under the heading "Effect of Fertilizers".

PRELIMINARY SURVEY, 1929

SOURCE OF MATERIAL

In order to determine the range in strength and amount of variability to be expected during one season, 194 wheat samples were collected from 41 counties scattered throughout Ohio. The group included 70 Fulhio and 124 Trumbull samples. They were obtained through the aid of the Agronomy Department of The Ohio State University, Smith-Hughes teachers, county agents, extension agronomists, and others. It was hoped that a study of the samples would aid in the formation of a wheat zone map for Ohio and would also provide material for a statistical study of the relationships existing between the different measurements made upon the samples during the process of determining their strength[2] and suitability for the milling and baking industry.

ANALYTICAL PROCEDURE

As the samples were received they were allotted a milling number and forwarded to the laboratory where they were stored, free from insects and vermin, in covered containers. They were subjected to the following routine procedure:

1. The sample was thoroughly cleaned by passing through a small fanning mill, after which the weight per measured bushel was determined. The grain was not scoured. Notes were made if the sample gave evidence of being unsound.

2. A portion of the wheat was ground into meal. Then, (a) the moisture in the sample was determined, using the air over method (1 hour at 130° C.) as described for flour in "Methods for the Analysis of Cereals and Cereal Products" by the American Association of Cereal Chemists (1), and (b) the protein content was determined by approved methods (1).

3. Approximately 2500 grams of cleaned wheat were placed in glass jars fitted with screw tops and rubber washers. Sufficient water was added to temper the wheat to approximately 15 per cent. The amount varied, depending upon the type of wheat. Soft weak samples, such as the Michigan white wheats, received less temper than harder and stronger samples, such as Purkof or Red Rock. The tempering water was added in two portions, the first portion being sufficient to bring the moisture content to approximately 13.5 per cent and the remainder being added a short time before milling.

4. The tempered wheat was milled on a two-roll Allis-Chalmers experimental mill by a miller of over 30 years' experience in commercial mills. The corrugated rolls had 14 and 20 corrugations to the inch, respectively. During the milling process two grades, "patent" and "low grade" flour, were produced. If the patent flour proved to have too low an ash content, sufficient of the low grade was added to bring the final "straight grade" product to the desired ash

[2] "Strength" in flour has been defined in many ways, but the definition of Humphries (30) is the one most commonly used. Humphries defines strength as "the capacity of the flour to make large, well piled loaves". Bailey (7) suggested that the strength of flour is determined by the ratio between (a) the rate of production in and (b) the rate of loss of carbon dioxide from the fermenting mass of dough. Strength differs from "quality" in that high quality depends upon the use to which the flour is to be put. For breadmaking, strength and quality are positively correlated; for cake manufacture a weak flour is high in quality; for cracker production a medium strong flour gives best results in the initial sponge, while a weaker flour is more satisfactory in the final dough. This difference between quality and strength must be remembered. In the Tri-State territory high quality for cracker manufacture will be represented by the medium strength flours coming from wheats typical of this area—i. e., soft red winter wheats. For cake and pastry the soft white wheats grown so admirably in Michigan will have excellent quality although they lack strength for breadmaking.

content (0.43-0.45 per cent). If the patent flour itself possessed too high an ash content, naturally no low grade was added. The flour yield was calculated as the percentage of 15 per cent moisture content, straight grade flour based on the weight of cleaned and tempered wheat used in the milling sample. The flour yield does not include the small amount of low grade flour which was discarded.

5. The flour was placed in Mason jars after being thoroughly mixed by passing through the 12XX sieve and aged for approximately one month. All flours were aged about the same length of time.

6. The flours were tested for crude protein, ash, and moisture by approved methods (1).

7. Percentage absorption was determined by adding distilled water to 25 grams of flour (15 per cent moisture basis) until a dough of the correct consistency was obtained. The dough was mixed in a glazed cup with a spatula.

8. For the moisture basis used in stating results, the conversion tables given in the A. A. C. C. "Methods for the Analysis of Cereals and Cereal Products" (1) have been employed throughout in converting all protein, absorption, and ash percentages to a 15 per cent moisture basis.

BAKING TEST

During the course of the project one of the serious handicaps to the laboratory testing has been the lack of an official, standardized baking test suitable for testing soft wheats. The method given below was that employed on the 1929 and 1930 crops only. The methods used with succeeding crops are outlined on Page 17.

All ingredients and vessels were brought to a uniform temperature of 80° F. (26.67° C.) by placing them in the proofing chamber overnight. A straight dough method was used, the mixing being done by machine and the following formula being employed:

Flour	340 grams
Sugar	15 grams
Salt	6 grams
Yeast (Fleischmann)	15 grams
Tap water	Sufficient for predetermined absorption figure
Flour and dough temperature	80° F.
Time to first punch	50 minutes
Time to second punch	20 minutes
Proofing temperature	95° F.
Proofing time	50 minutes
Baked for about 35 minutes at	220° C.

A small Hobart "Kitchen-Aid" machine was used for mixing the dough. Punches, molding, and panning were done by hand. The volume of the loaf was determined by the customary displacement method, using a graduated home-made machine operating on the hour-glass principle. Loaves were cut 1½ hours after baking and scored for grain, texture, and color of crumb.

As a means of reducing errors due to a possible variable yeast supply, a special daily shipment of yeast was obtained directly from the Fleischmann Company in Chicago. At the factory this shipment was specially wrapped in cloth and then covered with wax to prevent losses by evaporation and to ensure freedom from outside contamination. The waxed package was then packed in sawdust and ice; this enabled it to reach the laboratory at a uniform temperature and in good condition. This yeast was used in both baking and fermentation tests.

FERMENTATION TEST

One hundred grams of flour on a 14 per cent moisture basis were made into a dough, using the Hobart "Kitchen-Aid" machine, according to the following basic formula:

Flour	100	grams
Salt	1.2	grams
Sugar	3.5	grams
Yeast (Fleischmann)	4.0	grams
Distilled water	55	cc.

All ingredients previously warmed to 80° F.

The dough was carefully placed in a lightly greased, 1000 cubic centimeter capacity Chidlow jar and this was then placed in a specially constructed Freas cabinet automatically regulated for both temperature and humidity. The dough was allowed to ferment at a temperature of $80 \pm 1°$ F. and a relative humidity of 90 ± 5 per cent. Following the 1929 crop some changes were made in the fermentation test procedure; these changes are given on Page 17. After the dough had been in the cabinet one hour, the volume of the fermenting dough was noted every 15 minutes until no further rise was observed or the dough fell. At this point the dough was carefully punched down in such a manner that the mass was free from bubbles. It was replaced in the cabinet and its volume again noted every 15 minutes until no further rise occurred or the dough fell. The same procedure was followed with another sample of the same flour on the next day and was repeated daily until suitable checks were obtained; ordinarily two determinations were sufficient. The volumes with their corresponding times were used as points in forming a curve plotted on graph paper ruled in inch and one-twentieth-inch squares. The volumes in cubic centimeters were plotted as ordinates against time in minutes as abscissae; each inch of the vertical scale represented 100 cubic centimeters and each inch on the horizontal scale represented 30 minutes. A double curve resulted. In order to obtain a single unit measurement, recourse was made to an instrument common to engineers, the planimeter. The area beneath both curves was measured in square centimeters. This figure, "A" in the tables, represents a relative measure of the strength of the flour insofar as its fermentation tolerance is concerned. The larger "A" is, the greater is the tolerance.

It should be noted that the curve represented by the rise during the first hour is omitted, as are volumes below 200 cubic centimeters. The former was found to be practically the same in all cases after a large number of observations had been made, and the latter represents the ordinary volume of the dough when punched down in the type of Chidlow jars used. Elimination of these two features aids in fitting the test into a routine laboratory procedure where large numbers are necessarily being handled simultaneously in a systematic manner.

RESULTS AND DISCUSSION

In Table 2 are given the summary data obtained on these farm-grown samples. More complete individual results have been presented elsewhere (9). It will be observed that the State has been subdivided into five districts. The divisions were made largely as a result of a study of the soils and acreage of wheat abandoned due to winter and spring injury over the State. Figure 1 shows the counties included in each district.

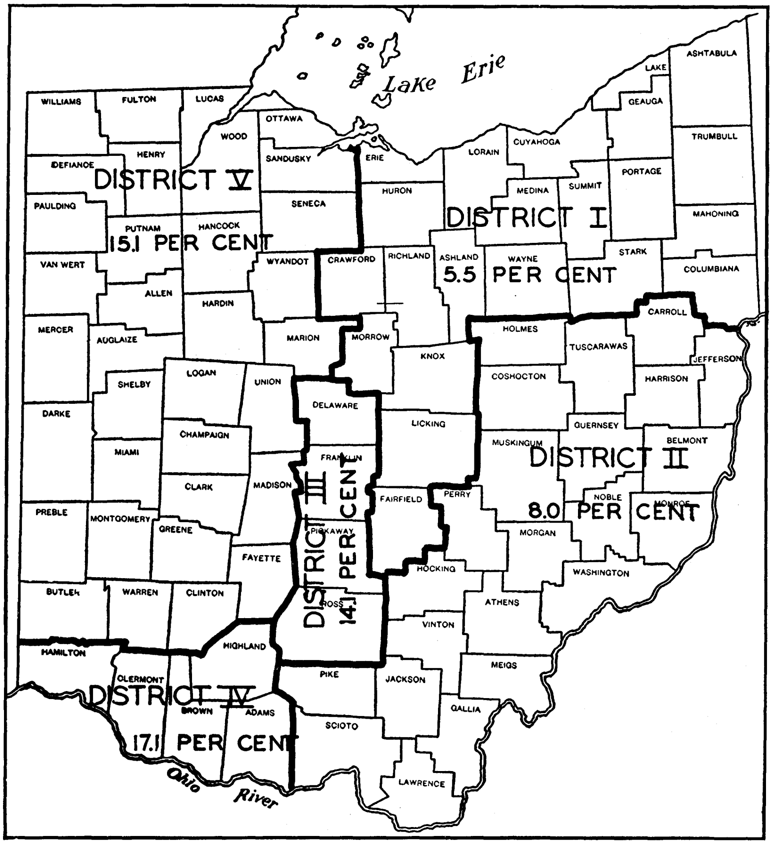


Fig. 1.—Map of Ohio showing the percentage of winter wheat abandoned by districts. (6-year average for 1924-25-26-27-29-30)

The 1929 crop data indicate a lower strength wheat area in northeastern Ohio (District I). Soils in the western half of the State derived from limestone of the Wisconsin Glacial Drift (District V) gave evidence of being the strongest. Districts II and IV had too few samples to draw definite conclusions, although the latter area fits into the theory that more fertile, limestone-derived soils tend to produce the stronger wheats.

Table 2 shows that Fulhio is weaker (smaller loaf volumes and lower "A" values) than Trumbull although Fulhio possessed slightly more protein than the latter variety. It was thought that the uneven distribution of the two varieties in the different districts might be causing the differences obtained between the various districts. Accordingly, new averages for the various divisions were made using the Trumbull data alone. The resulting figures gave the same general conclusions as already given for the larger group consisting of the two varieties together.

TABLE 2.—Ohio 1929 Preliminary Survey (Trumbull and Fulhio)

County	Samples averaged	Weight per bu.	Protein in wheat	Loaf volume	Fermentation "A"
	No.	*Lb.*	*Pct.*	*Cc.*	*Cm.*[2]
Cuyahoga	2	56.80	9.32	1670	182
Erie	2	59.45	9.04	1720	137
Fairfield	1	55.80	7.62	1770	159
Knox	16	57.77	8.47	1747	147
Lake	1	59.70	11.06	1750	112
Licking	2	56.65	8.00	1595	158
Mahoning	7	59.83	10.04	1690	128
Medina	1	59.60	9.97	1640	121
Morrow	8	57.51	8.54	1806	176
Stark	4	59.67	10.47	1762	150
Summit	3	61.33	10.03	1677	113
Trumbull	6	59.48	9.93	1842	158
Wayne	24	57.87	9.01	1773	165
Average, District I	77	58.34	9.13	1753.8	153.9
Holmes	1	57.30	7.52	1670	145
Meigs	8	59.56	9.17	1847	204
Washington	3	58.47	9.46	1740	141
Average, District II	12	59.10	9.10	1805.0	183.3
Delaware	3	57.20	8.47	1673	178
Franklin	21	57.53	8.64	1807	146
Pickaway	15	56.98	8.72	1797	159
Ross	1	58.10	8.85	1680	131
Average, District III	40	57.31	8.66	1790.0	152.9
Brown	1	56.70	8.79	1820	144
Clermont	4	56.47	8.87	1755	162
Hamilton	4	55.07	10.35	1815	136
Average, District IV	9	55.87	9.52	1788.8	148.4
Butler	1	57.50	9.06	2200	168
Champaign	2	54.65	10.25	1945	115
Clark	8	57.05	9.02	1975	176
Darke	1	59.50	9.18	1700	135
Fayette	1	58.00	8.28	1860	162
Fulton	5	59.18	9.52	1832	152
Hardin	1	58.40	8.34	1760	121
Logan	1	57.30	9.65	1880	144
Lucas	2	58.05	9.58	1965	164
Madison	3	57.50	8.64	1727	126
Marion	6	57.82	8.83	1762	144
Mercer	1	57.70	7.99	1590	135
Miami	3	57.47	8.92	1727	143
Montgomery	2	59.00	9.49	1820	132
Seneca	3	57.40	8.80	1627	162
Union	1	57.10	8.85	1810	165
Wood	10	58.24	9.44	1904	146
Wyandot	2	57.35	10.22	1730	125
Average, District V	53	57.78	9.18	1840.3	148.8
State average for Fulhio	70	58.06	9.18	1747	147.4
State average for Trumbull	124	57.75	8.98	1814	157.0

Examination of the fermentation "A" data indicates considerable disagreement with strength of samples as measured by baking results. These inconsistencies were found in later seasons also, and statistical studies have since shown that the fermentation test is less reliable for measuring strength than the baking test.

The principal reason for undertaking the 1929 survey was to obtain data which would aid in zoning the State; however, only 41 of the 88 Ohio counties were sampled. The problem of how to divide the State into various areas according to strength, using loaf volume as a measure, presented several obstacles, not the least of which was the fact that all counties were not represented in the survey. It was hoped that, if a suitable zoning scheme were worked out for Ohio, the scheme could later be extended to cover the entire Tri-State Territory.

Several different zoning schemes were tried with varying success. Finally, it was observed that the percentage of winter wheat abandoned according to the May first crop reports fitted reasonably well with a generalized soil map of the State. These abandonment figures are collected by the United States Department of Agriculture Crop Reporting Service by counties through cooperating farmers. County figures, however, have not been published owing to the fact that many counties are represented by too few reports to give reliable averages. Considered for a period of years however, they do give valuable information. Through the courtesy of Mr. A. R. Tuttle, Statistician of the Bureau of Agricultural Economics, Columbus, Ohio, the writer was given access to the original records. Six-year averages were computed for the period 1924 to 1930, inclusive; the year 1928 was excluded because it would have weighted all the results unduly on account of the very large acreage of winter wheat abandoned in that abnormal year. The county figures as such are not presented as it was not desired that they be published.

While the amount of winter damage occurring in the wheat crop may not have any connection with the quality of the threshed grain coming from that portion of the crop which survives the winter, yet it is believed that these abandonment figures give an indication of the environment in which the crop grows. Thus, in counties with a heavy type of soil and poor drainage, such as Ashtabula and Trumbull in northeastern Ohio, we find increased losses as compared with adjacent counties having lighter textured soils. Again, those counties with rolling topography and good natural drainage normally showed less abandonment than more level counties in the same climatic zone. The hilly region of southeastern Ohio is rougher than the glaciated areas to the north. The soils in this area are frequently low in fertility and this tends to increase the amount of abandonment and more than offset the good influence of drainage on the slopes and better drained areas. Furthermore, there occurred a decided increase in abandonment as soon as one left the sandstone and shale areas (20) [whether residual (26) or glaciated (23, 25)] and approached the limestone (21, 22, 24) half (western) of the State. Probably the subsoils in the latter area are of heavier texture and less well drained than the former. We have already seen that the latter area gave the stronger wheat in 1929. This may have been a coincidence, but, as will be noted later, the crop data show that the two quality series grown on the Miami soil had the largest average amount of protein of any grown in Ohio.

After consideration it was decided to use these abandonment figures, which gave a uniform sampling for all counties, as a basis for an initial zonation of the State. Figure 1 gives the five general districts into which the State was divided. Naturally, county lines do not agree with soil boundaries, but the divisional lines for the districts agree reasonably well with the main soil divisions considered. This agreement may be noted by examining the generalized soil map (Page 35a) for the three states.

District I consists of the glaciated sandstone and shale section of Ohio (23, 25). In this area the Wooster and associated soils are the best for wheat production. This district has the lowest abandonment in Ohio, amounting to 5.5 per cent. Table 2 shows that in 1929 it produced the weakest wheat (average of 77 samples). In this area Geauga, Trumbull, and Mahoning Counties have soils considerably heavier than in the remainder of the counties. They also show greater winter wheat abandonment although not as great as in counties with heavy soils in northwestern Ohio where there is less snow cover.

District II is principally the residual sandstone and shale area of the State (26). It has the second lowest winter wheat abandonment, amounting to 8.0 per cent. Muskingum silt loam is the predominant upland soil. Only twelve samples were received from this area in 1929; moreover, due to the fact that eight of these came from one county (Meigs), it is probable that a representative sampling of the area was not obtained. The other two counties gave results quite different from Meigs.

District III consists of soils largely transitional between the glaciated limestone (21) to the west and the sandstone-shale soils to the east. The four counties in this group are fairly evenly bisected by the line representing the boundary between the glaciated limestone and glaciated sandstone and shale areas. Since it was not known exactly on which soil the wheat was grown, it was necessary to form this separate district. Its abandonment percentage of 14.1 indicates its transitional character, as will an examination of the averages in Table 2.

The inclusion of District IV with a winter abandonment of 17.1 per cent may not be justified. It is a small territory comprising four counties consisting largely of the oldest glaciated limestone soils in the State. A part of Adams County is residual limestone, the remainder being derived from glacial Illinoian Drift and possessing a deeply leached soil of low natural fertility. The predominant soils of District IV are the Clermont and Rossmoyne silt loams. The nine samples of wheat received were rather inferior in grade, with a low test weight of 55.87 pounds per bushel, but possessed a high average crude protein content. The quality of protein, however, did not prove to be as good as in a better grade of wheat; also, these samples were the lowest in strength, when considered from the standpoint of either loaf volume or fermentation "A". This is in agreement with the well known fact that low test weight wheat normally gives poorer results than its protein analysis would indicate, due principally to the change in the relative proportions of endosperm to pericarp.

District V comprises 35 counties in Western and Northwestern Ohio with a 15.1 per cent winter wheat abandonment. The soils are of glacial limestone origin with the northern portions principally lacustrine. In this latter area Paulding, Defiance, Putnam, Wood, and Ottawa Counties possess a high percentage of clay soils. Owing to the risk of winter loss, some spring wheat is still grown in these counties. The soils in Williams and, to a less extent, Fulton and Lucas Counties tend to resemble those of southern Michigan, which has less winter injury than Ohio. The 53 samples received from District V gave the highest average loaf volume for the State. With a mean difference of only 0.05 per cent crude protein it exceeded District I by 86.5 cubic centimeters in loaf volume. In view of the number of samples this should be a significant difference.

While a wheat survey similar to that carried out in 1929 in Ohio was not made in Indiana and Michigan, the findings from Ohio should hold in a general way for these two adjacent states, modified of course by local conditions. In order to study the relation of wheat abandonment to the strength of wheat grown in Indiana and Michigan, abandonment averages by counties were prepared for the same period as used in Ohio. The writer is indebted to Mr. Miner M. Justin, Agricultural Statistician, Crop and Livestock Reporting Service, Lafayette, Indiana, and to Mr. Irwin Holmes, Agricultural Statistician, Michigan Cooperative Crop Reporting Service, Lansing, Michigan, for the individual county figures. The heavier snowfall in Michigan causes much less abandonment than in either Ohio or Indiana. Michigan counties with heavy soils, however, show about twice as much abandonment (5-9 per cent) as counties which apparently are better drained. Indiana showed its area of heaviest abandonment to be a continuation of the same general soil area, consisting largely of Brookston and Crosby silt loams and silty clay loams, which showed highest abandonment in Ohio. Indiana is less uniform in soil features than Ohio and this makes the interpretation of the results more difficult.

Although it is recognized that future study may show that the foregoing scheme of zoning the states on the basis of wheat abandonment may not be justified, it is quite certain that such a scheme defines the areas which require the more winter hardy varieties. From these areas requiring the hardier forms of wheat the milling industry may expect the largest admixture of the hard red winter types, as the farmer will continue to grow these types until the plant breeder produces hardy soft winter varieties. From this viewpoint alone the effort in preparing the following Tri-State wheat abandonment map (Figure 2) is probably justified.

Examination of this map indicates very clearly the seriousness of winter and spring damage to the wheat crop. The problem of obtaining soft winter wheats of correct quality which, at the same time, are resistant to both cold (winter hardiness) and heaving (spring hardiness) is a very difficult one. It is the most serious wheat breeding problem in Ohio. The map shows Indiana as having less abandonment, but this may be due to the fact that over 10 per cent of the Indiana crop is of the hard red winter type which suffers less from the cold than the superior quality, soft red winter varieties.

The distribution of classes of wheat in 1929 (19) in Indiana shows more hard winter wheat in the central and northern sections of this State. Adjacent areas in Ohio grew very little of this class of wheat and show a higher amount of abandonment.

During the 25-year period of 1908-1932 inclusive, Ohio has had a higher percentage of wheat abandonment than any state bordering it. Table 3 contains averages from figures given in various Yearbooks of the United States Department of Agriculture.

TABLE 3.—Percentage of Wheat Abandoned, 1908-1932

	Per cent
Ohio	10.22
Indiana	10.12
Kentucky	8.99
Michigan	5.12
West Virginia	3.32
Pennsylvania	2.94

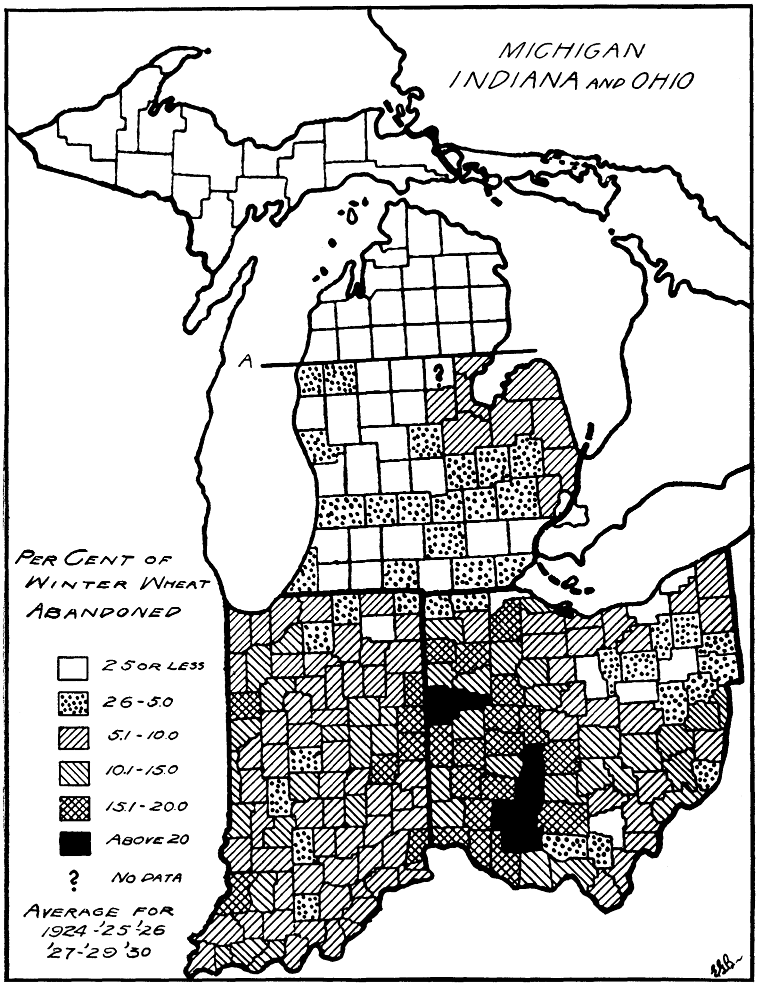


Fig. 2.—Percentage winter wheat abandoned by counties during 6-year period 1924-25-26-27-29-30. (Counties north of line "A" not included in survey)

Climatic conditions in Michigan are considerably different from the rest of the Tri-State Territory. Heavier snow cover and lighter textured soils help to reduce the amount of abandonment. The heaviest soils and highest abandonment occur on the lacustrine soils in the eastern part of the State. Apparently, the better drained and lighter textured soils experience less winterkilling and spring heaving. The heavy soils with poorer drainage, on the other hand, due to adverse conditions produce thinner stands of wheat in fields which are not abandoned. These fewer plants probably have a larger amount of soil nutrients available per plant, and this may account for the higher protein content which is often obtained in wheat produced on these heavy soils. At least, it has been found that heavy soil texture is frequently associated with a higher percentage of wheat abandoned, and these heavy soils on the average produce stronger wheat than lighter textured soils.

QUALITY SERIES, 1930-1933

SOURCES OF MATERIAL

A winter annual, such as fall-sown wheat, has a growing period occupying parts of 2 calendar years. In this study of factors influencing quality it is necessary to consider various factors entering into the environment under which the samples were produced. Quality in flour is largely determined from materials of colloidal nature which are produced during the growing and the ripening period. Since colloids are readily influenced by their environment, it may be expected that such factors as variations in weather, soil nutrient supplies, bad harvesting or storage conditions, and insect infestations will influence the quality of wheat or flour. For convenience, available Tri-State production and harvesting details are presented by separate states.

Ohio.—(a) In order to measure the influence of variations in soil type upon the quality of wheat within a given climatic environment, arrangements were made whereby five farmers in the vicinity of Delta, Fulton County, grew the "quality series" of varieties as a cooperative project. This set of varieties consisted of Trumbull, Nabob, Fulhio, American Banner, Red Rock, Berkeley Rock (1930 and 1931 only) or Bald Rock (substituted for Berkeley Rock in 1932 and 1933), Michigan Amber, Kharkov, Fultz, and Gladden. The last named variety was not included the first year of the test as sufficient seed was not available. Single plots were sown, using the farmer's seeding equipment. Each farmer, usually assisted by the author, planted the entire set of varieties using a rate of 2 bushels per acre. Approximately 300 pounds of 2-14-4 fertilizer per acre were applied. The plots occupied a part of the owner's field sown to wheat. The exact location of the plots was carefully determined beforehand to insure that the soil was uniform and of the desired type. Notes were taken for condition of growth in the fall and again in the spring, so that winter damage could be noted. In this respect, very little difference existed between the sets of plots in Fulton County, excepting in 1930 when Location 5 completely and Location 3 partially killed out.

(b) Plantings in Ohio for studying the effect of climate consisted of nine sets of the quality series, one being located on a medium textured soil in each of the following counties (Table 4)—Trumbull (1930 only), Henry (replacing Trumbull in 1930, 1931, 1932), Mahoning, Wayne, Knox, Franklin, Miami, Hamilton, Meigs, and Belmont. The Trumbull and Knox County plantings, as in Fulton County, were carried out cooperatively with farmers; the remainder were located on either state or county farms. These latter plantings received the fertilizer treatment deemed best for the particular field in question; the two former plantings received the same treatment as those in Fulton County. Winter damage was not severe during the 4-year period, excepting at Location 15 which completely killed out in the spring of 1930.

TABLE 4.—Plot Locations and Weather Stations

Location No.	County	Town	State	Weather station
1........	Fulton	Delta	Ohio	Wauseon
2........	Fulton	Delta	Ohio	Wauseon
3........	Fulton	Delta	Ohio	Wauseon
4........	Fulton	Delta	Ohio	Wauseon
5........	Fulton	Delta	Ohio	Wauseon
6*.......	Henry	Holgate	Ohio	N. W. Experiment Farm
7........	Trumbull	Brookfield	Ohio	Warren
8*.......	Mahoning	Canfield	Ohio	Mahoning County Experiment Farm
9*.......	Wayne	Wooster	Ohio	Ohio Agricultural Experiment Station
10........	Knox	Fredericktown	Ohio	Mt. Vernon
11*.......	Franklin	Columbus	Ohio	Ohio State University and Columbus
12........	Miami	Troy	Ohio	Miami Co. Experiment Farm (in part)
13*.......	Hamilton	Mt. Healthy	Ohio	Hamilton Co. Experiment Farm
14*.......	Meigs	Carpenter	Ohio	S. E. Experiment Farm
15*.......	Belmont	St. Clairsville	Ohio	Belmont Co. Experiment Farm
16........	Jennings	North Vernon	Indiana	Butlerville
17*.......	Lawrence	Bedford	Indiana	Bedford
18*.......	Tippecanoe	Lafayette	Indiana	Purdue University
19*.......	Kalamazoo	Augusta	Michigan	Gull Lake (Kellogg Farm)
20*.......	Ingham	East Lansing	Michigan	Michigan State College
21*......	Missaukee	Lake City	Michigan	Lake City (near)
22........	Branch	Quincy	Michigan	Coldwater
23........	Branch	Union City	Michigan	Coldwater
24........	Ingham	Mason	Michigan	Michigan State College
25........	Clinton	Eagle	Michigan	Michigan State College
26........	Ionia	Lake Odessa	Michigan	Saranac
27*.......	Monroe	Monroe	Michigan	Monroe Co. Experiment Farm
28........	Sanilac	Marlette	Michigan	Croswell
29........	Branch	Coldwater	Michigan	Coldwater
30........	Lenawee	Jasper	Michigan	Morenci

*Locations used in climatic studies.

Yield-per-acre data from these Ohio plots were obtained by two different methods. The county and state farms harvested and threshed their plots in the customary fashion, the desired yields and samples being forwarded to the author as they became available. Yield data from the plots grown cooperatively were obtained from four carefully selected representative rod rows harvested by hand. Each rod row was placed in a muslin bag and trucked to Wooster where, when dry, it was threshed in a rod row thresher and weighed. From these grain weights the average yield per acre was calculated. After the harvesting of the rod rows the owner cut the plots in the usual manner. During this harvesting operation 10 or 12 representative bundles of each variety were selected and trucked to Wooster or Holgate where they were placed in covered shocks and allowed to cure in normal fashion. In due course they were threshed on a plot thresher and stored until ready for analysis.

Indiana.—Each year all or a part of the quality series of varieties was grown at a number of Indiana locations. The maximum number of counties, Laporte, Marshall, Huntington, Randolph, Jennings, Lawrence, Greene, Knox, and Tippecanoe, was represented in the 1930 harvests. Milling samples and pertinent agronomic information from these various locations were obtained through the courtesy of W. W. Worzella, National Milling Company Fellow for Indiana. Unfortunately, at only three Indiana locations (Table 4) was the entire quality series grown uniformly during the period. The remainder of the data has, therefore, not been included in this study.

Michigan.—Table 4 shows a large number of plot locations for this State. Many of these locations were used in a single year only. At least six locations were harvested each year by the National Milling Company Fellow for Michigan. For the resulting samples, as well as pertinent agronomic data, the author is indebted to C. P. Wilsie (1929-1930 Fellow) and Grover Brown (1931-1933 Fellow).

CHANGES IN ANALYTICAL PROCEDURE, 1930-1933

With increasing experience and various supplementary experiments certain changes were made during the period. The milling procedure outlined for the 1929 samples was essentially that followed although tempering methods were changed as required by the varying characteristics of the different annual crops. Good practices were followed by the same miller during the entire 5-year period.

Routine determinations, such as for protein, ash, moisture, and absorption, were made as already outlined.

Several changes were found advisable in the baking test. A major change occurred in 1931 when the small "pup" loaf using only 100 grams of flour was substituted for the larger loaf (340 grams of flour) used for the 1929 and 1930 crop samples. Details as to baking formulae and procedures have been published in the Annual Reports of the Tri-State Soft Wheat Improvement Association (46, 47, 48, 49) and elsewhere (13, 17) so that they need not be given here. The "pup" loaves have been found quite satisfactory and a desirable improvement for testing experimental samples.

The fermentation or expansimeter test was run on all samples grown in the 1929-1931 period and on a part of the 1932 samples. Various changes were made in procedure before finally discontinuing the tests entirely. The test is an adaptation of the old Baker's Sponge Test used by Snyder (41), Shephard (40), and Norton (37). The 1929 crop results obtained with the test were not very satisfactory. The fixed absorption figure (55 per cent) used in 1929 gave doughs which were either too slack or too stiff in some cases. The 1930 samples were therefore run using a variable instead of a fixed absorption; otherwise, the method was unchanged. The 1931 samples were tested by using one-half of the dough (200 grams of flour) used in the baking test (17) and performing the test at 30° C. Individually mixed doughs were employed for the 1932 samples (13).

RESULTS AND DISCUSSION

In presenting the 4 years' results obtained on the quality series, only averages for the various series are given in the tables. In the Appendix are presented the individual results for yield per acre, test weight per bushel, wheat protein, and loaf volume. Individual flour protein figures have not been given, as it has been found that flour protein is closely associated with the protein content of the wheat from which the flour was milled. For example, the correlation coefficient for protein in wheat with protein in flour calculated for 100 samples of the 1933 crop equaled +0.9922.

Before considering the data it might be well to digress long enough to define the two terms "quality" and "strength" of wheat or flour as used in this publication.

It is principally strength which is under investigation. The term "quality" when applied to wheat has many possible meanings. The term must be considered in relation to the purpose for which the wheat or flour is to be used; thus, a high quality wheat for cake or pastry flour would be a low quality wheat for the milling of a strong bread flour. Test weight per bushel, diastatic activity, percentage crude protein, strength of gluten, suitability for intended use, and many other factors enter into the term "quality" in wheat or flour.

Strength in wheat has been defined as the capacity of a flour from such wheat to produce, in the presence of an adequate gas supply, large, well-piled loaves of bread. For bread wheats, therefore, quality and strength are more or less interchangeable terms. Strength in wheat is determined largely by the quantity and quality of its protein. A wheat may be strong due to a moderate amount of high quality protein or to a larger amount of protein of inferior quality. The quantity factor in wheat strength, measured by the protein test, is more important than the quality factor in our widely grown, superior varieties of wheat. These superior varieties of wheat possess suitable protein qualities for the purpose for which they are to be used. The quality of protein in American Banner is different from that in Trumbull, and yet for some purposes the weaker American Banner commands a premium in price on the market.

The principal factors which influence wheat strength are climate, soil, and variety. Of these, climate produces the greatest amount of variation in strength, and variety produces the least. Variety very largely determines the quality of the protein; whereas all three factors influence the quantity of protein. The average quality of the varieties included in the quality series is good. As the same varieties were grown, with but few exceptions, at all locations in each year, the variations due to environment may be measured by the average protein content of the wheat produced. The higher the average wheat protein content, therefore, the stronger will be the flour resulting from milling this wheat.

CLIMATE AND WHEAT STRENGTH

Climate is the most important environmental factor influencing wheat strength. Rainfall and temperature data were available from a large number of weather stations in the Tri-State territory. However, for several plot locations the weather station was located several miles from the plots. Preliminary studies indicated that such weather data, particularly rainfall, were not truly representative of the conditions existing at the plots. Accordingly, all plot locations that were not within a relatively short distance from the weather station were eliminated from this phase of the investigation. Furthermore, only plot locations which normally produced the entire quality series of varieties were included. Table 4 gives the various plot locations which grew these varieties. The nearest weather station is also given.

In studying the effect of rainfall and temperature, it was easily seen that calendar dates were of little value owing to the wide area over which the crops grew. Thus, for example, in 1930 the crop at Hamilton County, Ohio, was harvested June 20 while the same varieties were not ready for cutting until July 22 on the Missaukee County, Michigan, plots. This represents the extreme range found between dates of harvesting (Table 5). In order to eliminate these differences in calendar dates and thus to make the climatic conditions comparable insofar as the development of the wheat crops was concerned, the total rainfall and mean daily temperatures were calculated by 5-day intervals for the 50-day period preceding the date of harvest. It seemed as though this period should largely cover the critical periods in the development of the wheat grain. Normally, approximately 30 days are required from the date at which the plant is headed until the time it is ripe and ready for harvest. About 40 days before harvest the plant is in the boot stage and ready to head out. Naturally, the filling and desiccation periods vary somewhat in duration, depending upon the season in which the crop is grown.

TABLE 5.—Dates of Harvesting Tri-State Quality Series

Location No.	County	1930	1931	1932	1933
1	Fulton, Ohio	July 4	July 4	June 28	June 28
2	Fulton, Ohio	July 5	July 6	June 29	July 1
3	Fulton, Ohio	July 6	July 4	June 30	July 3
4	Fulton, Ohio	July 6	July 7	June 30	June 29
5	Fulton, Ohio	No crop	July 6	June 30	June 29
6	Henry, Ohio	....	July 3	June 29	June 30
7	Trumbull, Ohio	July 15	....	....	....
8	Mahoning, Ohio	July 14	July 10-11	July 11	July 5-6
9	Wayne, Ohio	July 2	July 6	July 1	June 30
10	Knox, Ohio	July 3	July 2	July 2	June 30
11	Franklin, Ohio	June 30	July 3	July 5	June 29
12	Miami, Ohio	July 1	July 3	June 25	June 24
13	Hamilton, Ohio	June 20	June 30	June 24	June 22
14	Meigs, Ohio	June 26	July 4	June 25	June 24
15	Belmont, Ohio	No crop	July 11	July 2	July 5
16	Jennings, Ind.	June 27	June 29	June 30	June 26
17	Lawrence, Ind.	June 23	June 27	June 25	June 21
18	Tippecanoe, Ind.	June 26	July 2	June 28	June 26
19	Kalamazoo, Mich	July 9	July 16	....	July 5
20	Ingham, Mich.	July 12	July 9	July 10	July 9
21	Missaukee, Mich.	July 22	July 17	July 18	July 15
22	Branch, Mich.	July 11	....	....	....
23	Branch, Mich.	July 7	....	....	....
24	Ingham, Mich.	July 17	....	....	....
25	Clinton, Mich.	....	July 11	....	....
26	Ionia, Mich.	....	July 8	....	....
27	Monroe, Mich.	....	July 9	July 9	July 6
28	Sanilac, Mich.	....	....	July 20	July 18
29	Branch, Mich.	....	....	July 7	....
30	Lenawee, Mich.	....	....	July 8	July 7

Tables 6 and 7 give total precipitation and mean temperatures, respectively, for various periods. In these tables the various locations have been arranged in groups of four and in descending order of protein content for each of the 4 years. It will be seen from Table 6 that wet weather during the heading period favors a low protein content in the wheat at harvest time, about 30 days later. Warm, dry weather during this period favors high protein, for such weather would favor the production of nitrates in the soil and these additional supplies would be moved into the wheat berry during the filling stage. Similarly, high-protein wheat may be produced by adding readily available nitrates to the soil at heading time in the form of a commercial fertilizer such as nitrate of soda. Heavy rains during heading time would not only discourage vigorous nitrate production by the soil nitrifying organisms but would also tend to leach away any nitrates which might be in the soil at the time.

TABLE 6.—Wheat Protein and Total Precipitation

(Tenth 5-day period ends at harvest)

	Crude protein	Precipitation by 5-day periods										10 days	15 days	20 days	50 days
Period ☞		1	2	3	4	5	6	7	8	9	10	3-4	2-3-4	2-3-4-5	1-10
Locations in group	Pct.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Season—1930*															
No. 19, 20, 11, 9	11.18	2.46	1.75	0.87	0.62	0.87	1.34	1.68	3.02	1.61	0.62	1.49	3.24	4.11	14.84
No. 9, 14, 18, 8*	10.05	1.04	1.92	1.69	1.98	0.69	0.07	2.32	0.48	3.60	1.54	3.67	5.59	6.28	15.35
No. 8, 21, 17, 13	9.39	2.20	0.03	1.04	2.26	2.31	0.61	1.70	0.31	2.33	1.29	3.30	3.33	5.64	14.08
Season—1931															
No. 13, 14, 19, 11	11.60	2.29	2.63	2.69	0.41	4.77	1.76	2.86	1.21	1.71	0.81	3.10	5.73	10.50	21.14
No. 20, 8, 9, 6	9.97	4.18	1.22	2.21	4.22	3.68	0.67	0.64	2.94	1.53	2.28	6.43	7.65	11.33	23.57
No. 27, 15, 17, 18	9.31	1.80	1.82	3.52	5.71	0.96	1.40	0.68	1.57	4.50	0.72	9.23	11.05	12.01	22.68
Season—1932															
No. 15, 8, 9, 11	12.90	1.10	0.10	0.60	0.34	2.67	1.07	1.96	4.46	4.30	7.16	0.94	1.04	3.71	23.76
No. 17, 6, 14, 21	10.01	3.07	1.39	0.03	2.05	1.14	2.27	2.39	2.36	2.56	1.85	2.08	3.47	4.61	19.11
No. 27, 20, 13, 18	9.59	0.94	3.41	1.56	0.22	1.12	2.31	0.84	2.82	2.75	2.77	1.78	5.19	6.31	18.74
Season—1933															
No. 6, 21, 27, 9	11.96	5.27	0.46	1.89	1.02	0.73	1.31	0.76	2.31	0.10	2.22	2.91	3.37	4.10	16.07
No. 20, 11, 18, 17	10.66	10.91	2.78	4.09	1.85	3.35	1.98	0.04	0.32	2.59	1.15	5.94	8.72	12.07	29.06
No. 14, 15, 13, 19	9.78	3.45	4.35	5.82	1.25	4.00	0.35	1.26	....	1.51	5.79	7.07	11.42	15.42	27.78

*Medium protein group includes lowest in high group and highest from low group.

TABLE 7.—Wheat Protein and Mean Temperature

(Tenth 5-day period ends at harvest)

	Crude protein	Temperature by 5-day periods										10 days	15 days	20 days	30 days	50 days
Period ☞		1	2	3	4	5	6	7	8	9	10	3–4	2–3–4	1–4	5–10	1–10
Locations in group	Pct.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Season—1930*																
No. 19, 20, 11, 9	11.18	59.6	54.5	62.6	56.8	69.0	65.0	72.2	68.7	70.7	71.6	59.7	58.0	58.4	69.5	65.1
No. 9, 14, 18, 8*	10.05	63.8	59.2	60.8	58.5	64.0	66.9	68.2	70.1	70.9	74.5	59.7	59.5	60.6	69.1	65.7
No. 8, 21, 17, 13	9.39	63.2	62.6	64.0	62.4	65.9	63.2	67.8	65.5	68.9	72.5	63.2	63.0	63.1	67.3	65.6
Season—1931																
No. 13, 14, 19, 11	11.60	63.6	60.9	60.8	67.6	68.3	68.7	74.1	76.3	77.7	80.1	64.2	63.1	63.2	74.2	69.8
No. 20, 8, 9, 6	9.97	55.5	58.7	61.0	60.8	64.8	66.1	69.7	73.8	77.8	76.1	60.9	60.2	59.0	71.4	66.4
No. 27, 15, 17, 18	9.31	55.7	66.3	62.6	64.1	68.8	68.7	72.9	76.2	81.2	81.4	63.4	64.4	62.2	74.9	69.8
Season—1932																
No. 15, 8, 9, 11	12.90	61.5	59.6	65.6	62.9	69.5	67.2	68.5	72.8	70.1	71.6	64.3	62.7	62.4	70.0	66.9
No. 17, 6, 14, 21	10.01	62.9	62.1	59.6	65.9	66.0	68.1	66.7	67.7	73.3	73.2	62.8	62.6	62.7	69.2	66.6
No. 27, 20, 13, 18	9.59	60.9	61.9	65.9	67.5	65.9	72.0	71.0	70.1	70.1	71.9	66.7	65.1	64.1	70.2	67.7
Season—1933																
No. 6, 21, 27, 9	11.96	62.7	64.6	68.8	67.3	69.0	74.0	71.4	68.4	75.5	75.0	68.0	66.9	65.8	72.2	69.7
No. 20, 11, 18, 17	10.66	61.4	65.0	67.6	72.8	69.1	71.1	76.4	73.7	75.5	77.4	70.2	68.5	66.7	73.9	71.0
No. 14, 15, 13, 19	9.78	61.7	67.5	65.5	66.9	75.7	65.8	71.3	79.1	72.8	76.3	66.2	66.7	65.4	73.5	70.3

*Medium protein group includes lowest in high group and highest from low group.

Table 7, giving the mean temperatures by various periods, indicates that under our climatic conditions temperature is not ordinarily a critical factor during the period under discussion. Temperature merely accentuates the effect of normal, subnormal, or excessive precipitation. The fact that protein formation is hindered by rainfall occurring a month or so before harvest may provide a means of forecasting the probable strength of the crop in advance of its harvest. In attempting such a forecast, however, one must consider the anticipated yield per acre, the amount of spring killing, and various other factors. Furthermore, if a given district is producing a mixture of wheat varieties, then the relative amounts of high- and low-protein varieties being produced in the district must also be considered. Low-protein varieties, such as Gladden, do not produce as much wheat protein from the available soil nitrates as do the high-protein varieties, such as Purkof or Michikof.

SOIL TYPES AND WHEAT STRENGTH

The study of the effect of soil type upon wheat strength over the 4-year period divides itself naturally into two parts: (a) where several soil types were planted within a small area each year and where the climate may be considered as being constant and (b) where a larger series of plot locations was scattered over the Tri-State territory. The wheats grown on this larger series were subjected to both soil and climatic differences. Table 8 gives the soils occurring on the various plots. Table 9 gives the average protein content of the samples grown on these various soils.

TABLE 8.—Soils at Various Plot Locations

No.	County	Soil series	Soil texture
1	Fulton, Ohio	Plainfield	Fine sand
2	Fulton, Ohio	Wauseon	Loamy fine sand
3	Fulton, Ohio	Nappanee	Clay
4	Fulton, Ohio	Brookston	Clay
5	Fulton, Ohio	Brookston	Clay loam
6	Henry, Ohio	Brookston	Clay
7	Trumbull, Ohio	Ellsworth	Silt loam
8	Mahoning, Ohio	Volusia and Canfield	Silt loam
9	Wayne, Ohio	Wooster	Silt loam
10	Knox, Ohio	Wooster	Silt loam
11	Franklin, Ohio	Miami	Silt loam
12	Miami, Ohio	Miami (some Crosby and Brookston)	Silt loam
13	Hamilton, Ohio	Russell (some Fincastle)	Silt loam
14	Meigs, Ohio	Muskingum	Silt loam
15	Belmont, Ohio	Muskingum	Silt loam
16	Jennings, Ind.	Clermont	Silt loam
17	Lawrence, Ind.	Bedford	Silt loam
18	Tippecanoe, Ind.	Brookston	Silt loam
19	Kalamazoo, Mich.	Fox	Sandy loam
20	Ingham, Mich.	Hillsdale (1930-1931) Conover (1932-1933)	Sandy loam (1930-1931) Loam (1932-1933)
21	Missaukee, Mich.	Nestor	Clay loam (1930-1931) Loam (1932-1933)
22	Branch, Mich.	Hillsdale	Sandy loam
23	Branch, Mich.	Fox	Sandy loam
24	Ingham, Mich.	Miami	Silt loam
25	Clinton, Mich.	Miami	Loam
26	Ionia, Mich.	?	Clay loam
27	Monroe, Mich.	? (1931), Conover (1932) Fox (1933)	Clay loam (1931) Loam (1932), sandy loam (1933)
28	Sanilac, Mich.	Conover	Loam
29	Branch, Mich.	Hillsdale	Sandy loam
30	Lenawee, Mich.	Brookston	Loam

TABLE 9.—Average Crude Protein in Wheat for 10 Varieties*
(Protein on a 15 per cent moisture basis)

No.	Location, County	Year				Samples	Average
		1930	1931	1932	1933		
		Pct.	*Pct.*	*Pct.*	*Pct.*	*No.*	*Pct.*
1	Fulton, Ohio............	10.08^{9}	8.62	9.56	9.00	39	9.35
2	Fulton, Ohio............	9.01^{9}	9.10	9.14	10.22	39	9.38
3	Fulton, Ohio............	9.13^{9}	9.09	9.53	11.55	39	9.84
4	Fulton, Ohio............	10.01^{9}	10.10	10.16	12.64	39	10.75
5	Fulton, Ohio............	....	9.97	9.50	11.37	30	10.28
6	Henry, Ohio............	....	9.74	10.13	13.60	30	11.16
7	Trumbull, Ohio.........	10.51^{9}	....	....	....	9	10.51
8	Mahoning, Ohio.........	9.67^{9}	9.95	12.85	10.58^{4}	33	10.83
9	Wayne, Ohio	10.43^{9}	9.86	12.58	11.15	39	11.02
10	Knox, Ohio..............	10.72^{9}	9.74	10.38	10.21	39	10.25
11	Franklin, Ohio	11.39^{9}	10.71	12.51	10.68	39	11.32
12	Miami, Ohio.............	11.14^{9}	11.16	12.12	11.11	39	11.39
13	Hamilton, Ohio	9.12^{9}	12.74	9.58	9.58	39	10.28
14	Meigs, Ohio	10.18^{9}	12.12	9.93	10.28	39	10.64
15	Belmont, Ohio...........	....	9.55	13.67	10.24	30	11.15
16	Jennings, Ind...........	12.57^{9}	9.24	10.07	10.58	39	10.56
17	Lawrence, Ind...........	9.34^{9}	9.38	10.28	10.42	39	9.87
18	Tippecanoe, Ind.........	9.91^{9}	8.60	9.46	10.52	39	9.61
19	Kalamazoo, Mich........	11.60^{8}	10.83	....	9.04	28	10.41
20	Ingham, Mich.	11.41^{7}	10.33	9.62	11.03	37	10.54
21	Missaukee, Mich.........	9.45^{8}	14.34	9.71	11.69	38	11.39
22	Branch, Mich............	10.11^{8}	....	....	....	8	10.11
23	Branch, Mich............	10.07^{8}	....	....	....	8	10.07
24	Ingham, Mich.	10.38^{6}	....	....	....	6	10.38
25	Clinton, Mich...........	....	12.55	....	....	10	12.55
26	Ionia, Mich.	....	11.69	....	....	10	11.69
27	Monroe, Mich.	....	9.72	9.70	11.34	30	10.25
28	Sanilac, Mich............	....	....	11.35	10.70	20	11.02
29	Branch, Mich............	....	....	9.62	....	10	9.62
30	Lenawee, Mich.	....	....	10.93	10.90	20	10.91
	No. of samples...............	180	230	230	224	864	....
	Average.....................	10.29	10.41	10.54	10.81	....	10.52

*Prime numbers refer to number of varieties included in average when less than the complete set of 10 varieties were grown.

Effect of different soils under a uniform climate.—Locations 1 to 5 in Fulton County, Ohio, each produced a complete set of the varieties each year, with one exception (Location 5) which completely winterkilled in 1930. Each of these locations was uniformly fertilized with 300 pounds of 2-14-4 fertilizer each year at the time of seeding. Planting and harvesting occurred at about the same time on the five different soils. Normally, it required about 3 to 4 days to harvest the five sets of plots, provided the weather did not interfere.

The Fulton County plots provide a number of comparisons. Comparing Locations 1 and 2 (light textured soils) with 3 and 4 (heavy textured soils), we find that heavy textured soils are associated with increasing protein. Sandy soils, therefore, will favor low-protein wheat. Locations 1 and 3 have light colored soils which are less fertile than the dark colored soils at Locations 2 and 4. In these cases the more fertile dark soils produce more protein than the same textured soils which are light colored and less fertile.

The range in protein from year to year is of interest. The Fulton County plots indicate that heavy-textured soils are more likely to produce a wider range in wheat protein than are lighter textured soils; thus, the dark colored Brookston clay soil (No. 4) produced wheat varying from 10.01 to 12.64 per cent during the 4-year period, or a range of 2.63 per cent. The dark colored Wauseon loamy fine sand in the same period varied from 9.01 to 10.22 per cent (range 1.21 per cent). The light colored Nappanee clay had a larger range (2.46 per cent) than the light colored Plainfield fine sand (range 1.26 per cent). It can, therefore, be expected that wheat produced on heavy soils will vary more between different years than when the same wheat is produced on lighter textured land.

Effect of different soils with climate a variable.—In making this comparison the entire group of 864 samples was subdivided according to the type of soil producing them; thus, the annual climatic effect tends to mask soil differences. The value of the averages is somewhat lessened by the fact that the same soil types were not used each year in Michigan. However, the data in Table 10 were obtained.

TABLE 10.—Effect of Soil Upon Protein Content, Yield, and Test Weight of Wheat

(Tri-State plots, 1930-1933, inclusive)

Soil	Samples	Protein	Test weight	Yield per acre*
	No.	*Pct.*	*Lb.*	*Bu.*
Sands	78	9.36	59.3	22.6
Sandy loams	81	10.44	60.7	29.2[79]
Loams	100	10.82	59.8	34.1[99]
Silt loams (Late Wisconsin Drift, limestone)	123	10.76	59.1	31.2
Silt loams (Late Wisconsin Drift, sandstone and shale)	120	10.68	60.3	32.8
Silt loams (Early Wisconsin Drift, limestone)	39	10.28	57.6	31.4[29]
Silt loams (Residual soils)	108	10.50	58.3	27.7
Silt loams (Illinoian Drift, limestone)	39	10.56	58.2	16.7[37]
All silt loams	429	10.61	59.0	29.5[417]
Clay loams	68	10.90	59.0	30.1
Clays (light colored)	39	9.84	60.0	29.1[29]
Clays (dark colored)	69	10.92	60.1	35.3[59]
All clays	108	10.53	60.1	33.3[88]

*Prime numbers refer to number of samples in average where less than all varieties were grown.

Examination of the protein figures indicates the same general trend as in the case of the samples grown under uniform climatic conditions. The results, however, are not as clear-cut, but this should be expected because climate and fertility of the soil of the various locations varied quite widely. Furthermore, the yield per acre influences the protein content considerably; for example, the protein content in the samples grown on the Early Wisconsin Drift soil (Russell silt loam) is relatively much lower than in the same wheats originating on the Illinoian Drift (Clermont silt loam) soil, although the latter soil is a poorer and less fertile soil than the former. However, the low yields per acre on the Clermont soil probably mean that relatively more soil nitrates are available for the smaller crop than for the larger yield obtained on the Russell soil. When all the clay soils are averaged, the apparently inconsistent results obtained are found to be due to the inclusion of the relatively infertile, light colored Nappanee clay soil with the more fertile, dark colored Brookston clays. The Nappanee soils are poorly adapted to wheat production. On these soils severe winterkilling is common.

From these results, it may be concluded that soil produces the following effects on protein content in wheat:

1. The protein increases with increasing heaviness—i. e., from sands to clays.

2. With a given soil texture (e. g., silt loam) the protein content will increase as the fertility of the soil increases.

3. If soil conditions early in the season favor heavy vegetative growth and heavy yields, low-protein wheat will result if the soil nitrate supply is deficient at filling time.

4. With unfavorable growth conditions early in the season and with a resulting small vegetative development, the protein content of the small crop harvested may be high if a plentiful supply of soil nitrates is available during the filling period.

5. With the right combination of nutrient supplies available from the soil, high yield per acre can be combined with high- or low-protein content and with normal test weight per bushel.

That soils do produce a definite influence upon protein content is further brought out by the averages presented in Table 11. These data were obtained by averaging certain of the Tri-State Protein Survey figures collected on the 1931-1932-1933 crops (11, 12, 14). The soil group numbers refer to the numbers employed on the Generalized Tri-State Soil Map (see Page 35a).

TABLE 11.—Some Data from the Tri-State Protein Survey

(1931-1932-1933 Red Winter cars only)

Soil group	Cars	Average protein
	No.	*Pct.*
3—Sands and sandy loams	111	10.12
5—Loams and sandy loams	505	10.61
13—Principally silt loams of Late Wisconsin Drift on sandstone and shale	441	10.13
8—Silt loams of Late Wisconsin Drift on limestone	1291	10.60
9—Silty clay loams of Late Wisconsin Drift on limestone	1117	10.80
6—Lacustrine clays	640	10.98

The figures in Table 11 corroborate the conclusions already presented; namely, that protein content in wheat tends to increase with increasing heaviness in texture and also with increasing fertility of the soil upon which the wheat is grown.

VARIETY AND WHEAT STRENGTH

The baking test gives the most universally accepted measure of wheat strength. Because a uniform weight of flour is employed in the baking test, the results are affected by both the quantity and the quality of the protein present in the flour. Protein quantity (percentage crude protein) has been shown to be positively associated with loaf volume obtained by means of the baking test. In testing new wheats today, there is no better available measure for estimating their strength. An adequate baking procedure must, however, be used. The following coefficients (Table 12) show that decided improvement has resulted from changes made in the baking procedure during the 5-year period. They also indicate that the formula being used at present is not perfect by any means.

TABLE 12.—Correlation Coefficients Between Flour Protein and Loaf Volume

Crop year	Number of samples	Correlation	
		No bromate	Plus bromate
1929	100	+0.4289	....
1930	224	+0.6136	....
1931	99	+0.6397	+0.7707
1932	100	....	+0.8247
1933	100	+0.6404	+0.7991

The fact that no adequate yardstick exists for measuring quality in soft winter wheat has already been mentioned. This lack has proven a serious handicap during the entire project and also explains why it was necessary to alter the baking procedure as experience indicated desirable changes. In order to make the data as comparable as possible, no bromated baking data have been included at this time (excepting 1932 data), although the bromated baking formula has given a superior measure of strength. Tables 13 and 14 present the data for the annual average baking results for each location. Four-year averages have not been presented, due to the variations existing in the baking methods in the different years; however, data within each year are com-

TABLE 13.—Average Loaf Volume for Ten Varieties

No.	Location, County	Year			
		1930	1931	1932	1933
		Cc.	*Cc.*	*Cc.*	*Cc.*
1	Fulton, Ohio	1735.5[9]*	417.2	520.5	545.3
2	Fulton, Ohio	1698.9[9]	432.8	526.4	619.1
3	Fulton, Ohio	1646.7[9]	443.6	536.6	629.1
4	Fulton, Ohio	1727.8[9]	459.9	518.5	631.0
5	Fulton, Ohio	....	439.9	515.6	616.9
6	Henry, Ohio	....	412.3	589.7	635.1
7	Trumbull, Ohio	1773.9[9]	....	....	....
8	Mahoning, Ohio	1757.8[9]	442.9	638.6	629.3[4]
9	Wayne, Ohio	1787.8[9]	444.3	592.8	612.5
10	Knox, Ohio	1799.4[9]	421.6	564.5	586.6
11	Franklin, Ohio	1894.4[9]	465.9	616.3	587.2
12	Miami, Ohio	1872.8[9]	453.7	632.5	584.5
13	Hamilton, Ohio	1640.0[9]	474.8	560.7	562.8
14	Meigs, Ohio	1707.8[9]	409.2	549.6	612.5
15	Belmont, Ohio	....	385.4	649.3	574.3
16	Jennings, Ind.	1863.3[9]	427.0	547.1	601.6
17	Lawrence, Ind.	1566.1[9]	457.0	529.0	594.0
18	Tippecanoe, Ind.	1707.8[9]	401.0	537.8	578.5
19	Kalamazoo, Mich.	1790.6[8]	501.5	....	534.9
20	Ingham, Mich.	1752.1[7]	511.9	548.0	661.7
21	Missaukee, Mich.	1647.5[8]	473.8	525.8	604.2
22	Branch, Mich.	1725.6[8]	....	....	....
23	Branch, Mich.	1698.7[8]	....	....	....
24	Ingham, Mich.	1672.5[6]	....	....	....
25	Clinton, Mich.	....	495.3	....	....
26	Ionia, Mich.	....	489.9	....	....
27	Monroe, Mich.	....	473.1	530.0	613.9
28	Sanilac, Mich.	....	....	599.5	620.5
29	Branch, Mich.	....	....	553.5	....
30	Lenawee, Mich.	....	....	528.6	586.9
	Average	1737.9	449.3	561.3	600.2

*Prime numbers refer to number averaged where fewer than complete set of 10 varieties were grown.

TABLE 14.—Average Loaf Volume for Various Varieties—1930-1933
(Tri-State plantings)

Year	Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average	Samples
	Cc.	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*No.*
1930	1766.4	1709.5	1723.3	1871.2	1616.4	1725.5	....	1698.7	1726.7	1800.0	....	1737.9	180
1931	464.9	444.1	460.9	460.8	426.6	446.1	....	444.8	450.3	444.0	450.4	449.3	230
1932	572.4	548.7	577.3	578.3	524.8	....	566.6	568.6	565.0	555.5	556.3	561.3	230
1933	608.5	592.3	611.6	622.1	560.9	....	605.6	588.7	603.1	599.7	607.9	600.2	224
Loaf volume rankings (Bald and Berkeley Rock excluded)													
1930	3	7	6	1	9	....	....	8	4	2	5*	....	....
1931	1	7	2	3	9	....	....	6	5	8	4	....	....
1932	3	8	2	1	9	....	....	4	5	7	6	....	....
1933	3	7	2	1	9	....	....	8	5	6	4	....	....
Average	2	8	3	1	9	....	....	7	4	6	4	....	....
Wheat protein rankings (Bald and Berkeley Rock excluded)													
1930	1	7	3	2	9	....	....	4	6	5	8*	....	....
1931	2	9	3	5	8	....	....	1	4	6	7	....	....
1932	1	7	3	6	9	....	....	1	4	5	8	....	....
1933	4	8	2	1	7	....	....	3	5	6	8	....	....
Average	1	7	3	4	9	....	....	2	5	6	7	....	....

*Estimated.

parable. Table 14 gives, in addition to the average annual loaf volume for each variety, the loaf volume and wheat protein rankings for the different varieties in order of decreasing strength. Berkeley Rock and Bald Rock wheats were only grown for two of the 4 years and have, therefore, been left out of the ranking arrangement. Gladden was not grown in 1930 but has been included by estimating its probable behavior in the missing year.

The nine varieties arranged in order of decreasing strength (according to loaf volume) are as follows: Red Rock, Trumbull, Fulhio, Kharkov and Gladden, Fultz, Michigan Amber, Nabob, and American Banner. In order of decreasing protein content they arrange themselves as follows: Trumbull, Michigan Amber, Fulhio, Red Rock, Kharkov, Fultz, Nabob and Gladden, and American Banner. A rough measure of protein quality is obtained by comparing the loaf volume ratings with the protein rankings. It is readily seen that, per unit of protein in Red Rock, larger volumes of bread are obtained than from Trumbull. Red Rock, therefore, may be considered as having a stronger (better quality) protein than Trumbull. Michigan Amber, on the other hand, has a relatively high content of protein which is rather poor in quality. Gladden is the opposite from Michigan Amber in that it is low in protein, but this small amount of protein is of good quality. American Banner and Nabob are low in both quantity and quality of protein.

The question of protein quality is of importance to millers, as wheat is frequently binned and blended upon a protein (quantity) basis. Fortunately, most of the varieties in the quality series are of reasonably satisfactory protein quality. Michigan Amber offers the greatest potential difficulty in a blend of the various wheats in the series because its protein content is not a good criterion of its strength. Berkeley Rock was discarded after 2 years' testing, during which time it proved to be an unsatisfactory milling wheat because it produced a high-ash, granular flour. Kharkov, the hard red winter representative, exhibits the low strength frequently found in this type of wheat when grown under a humid climate. This particular Kharkov stock, after growing for a long period in Ohio, no longer possesses the typical strength expected in a hard red winter variety.

TEST WEIGHT PER BUSHEL AND QUALITY

Weight per bushel is an important quality factor for the miller, in that it is associated with the possible yield of flour from each bushel of wheat milled. Normally, the heavier the wheat, the greater is the potential yield of flour. Many factors enter into and produce variations in the test weight; climate, soil, and variety each enter into the question.

A study of the test weight data in connection with the temperature and precipitation data during the 50-day period immediately preceding harvest indicates that the temperature during the latter part of this period has produced some changes in the test weight. Test weight varied inversely with increasing temperature during this period. The crop seasons in order of increasing test weight are 1931, 1933, 1932, and 1930. Since the greatest variation in test weight occurred in 1931, this season was selected to illustrate the relationship in detail (Table 15). It will be seen in Table 15 that the mean temperature during the last three 5-day periods varied inversely with the test weight to a greater extent than in the two earlier 15-day periods. However, it is doubtful whether the relationship has statistical significance. There seems to be even less relationship between total precipitation and test weight. Possibly the fact that considerable lodging occurred in 1931 may be a disturbing factor.

TABLE 15.—Average Test Weight (10 Varieties) and the Weather—1931 Crop
(Total precipitation and mean daily temperature from nearest weather station)

5-day periods*			2-3-4	5-6-7	8-9-10	2-3-4	5-6-7	8-9-10
No.	Location, County	Test weight	Temperature			Precipitation		
		Lb.	°*F.*	°*F.*	°*F.*	*In.*	*In.*	*In.*
13	Hamilton, Ohio......	52.5	62.8	66.5	77.6	1.05	1.88	1.18
12	Miami, Ohio.........	54.5	62.6	70.2	80.9	1.42	1.71	1.97
11	Franklin, Ohio	55.8	62.1	68.5	80.1	1.47	2.06	1.21
15	Belmont, Ohio.......	56.0	65.1	72.5	80.8	5.58	0.00	2.17
14	Meigs, Ohio.........	56.4	62.9	69.5	80.7	0.60	4.38	0.80
9	Wayne, Ohio	57.0	59.2	65.4	76.6	1.83	1.73	1.40
25	Clinton, Mich........	57.5	60.9	70.9	74.0	2.39	0.23	2.14
16	Jennings, Ind........	57.9	64.3	67.5	78.5	1.43	2.04	2.72
17	Lawrence, Ind.......	57.9	63.6	68.3	78.4	1.74	1.36	1.04
21	Missaukee, Mich.	58.0	62.5	70.7	69.4	0.38	1.28	0.06
10	Knox, Ohio	58.1	58.2	66.0	78.0	1.05	1.60	0.76
26	Ionia, Mich.	58.7	60.2	69.2	76.1	3.29	0.33	1.20
18	Tippecanoe, Ind.....	58.9	64.0	69.8	82.2	1.14	1.48	1.91
27	Monroe, Mich........	59.2	64.7	69.9	77.1	2.59	0.20	1.67
19	Kalamazoo, Mich....	59.7	64.6	77.0	73.8	2.61	1.07	0.54
4	Fulton, Ohio.........	59.7	67.5	70.1	78.5	4.12	0.15	2.51
6	Henry, Ohio.........	59.8	60.2	66.1	78.3	0.70	2.53	0.62
20	Ingham, Mich.	59.9	60.4	69.0	75.3	2.39	0.23	2.13
8	Mahoning, Ohio......	60.1	61.0	67.1	73.6	2.73	0.50	2.60

*See Tables 6 and 7; also Page 18.

TABLE 16.—Average Test Weight per Bushel for Ten Varieties*

No.	Location, County	Year				
		1930	1931	1932	1933	Average
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*
1	Fulton, Ohio...........	61.8[9]	58.9	58.3	58.7	59.4
2	Fulton, Ohio.........................	59.9[9]	59.4	58.6	59.0	59.2
3	Fulton, Ohio.........................	60.6[9]	59.4	60.5	59.7	60.0
4	Fulton, Ohio.........................	60.7[9]	59.7	58.9	59.5	59.7
5	Fulton, Ohio.........................	....	59.1	58.2	59.9	59.1
6	Henry, Ohio.........................	....	59.8	62.3	60.0	60.7
7	Trumbull, Ohio	60.9[9]	....	....	....	60.9
8	Mahoning, Ohio	61.2[9]	60.1	60.4	60.1[4]	60.5
9	Wayne, Ohio	62.4[9]	57.0	60.3	60.3	59.9
10	Knox, Ohio..........................	62.0[9]	58.1	61.1	60.5	60.4
11	Franklin, Ohio	60.5[9]	55.8	61.0	58.3	58.9
12	Miami, Ohio.........................	61.0[9]	54.5	60.0	57.3	58.1
13	Hamilton, Ohio......................	61.8[9]	52.5	59.4	57.2	57.6
14	Meigs, Ohio.........................	60.0[9]	56.4	58.8	58.6	58.4
15	Belmont, Ohio	....	56.0	60.3	59.4	58.6
16	Jennings, Ind........................	60.9[9]	57.9	56.8	57.6	58.2
17	Lawrence, Ind.	61.1[9]	57.9	57.6	56.2	58.1
18	Tippecanoe, Ind.....................	61.4[9]	58.9	60.9	58.8	60.0
19	Kalamazoo, Mich....................	61.4[8]	59.7	....	60.5	60.5
20	Ingham, Mich.	62.7[7]	59.9	59.2	59.3	60.1
21	Missaukee, Mich.....................	60.6[8]	58.0	60.5	61.6	60.1
22	Branch, Mich........................	62.6[8]	....	....	....	62.6
23	Branch, Mich........................	62.4[8]	....	....	....	62.4
24	Ingham, Mich.	60.7[6]	....	....	....	60.7
25	Clinton, Mich........................	....	57.5	....	....	57.5
26	Ionia, Mich..........................	....	58.7	....	....	58.7
27	Monroe, Mich.	....	59.2	58.5	60.4	59.4
28	Sanilac, Mich........................	....	....	59.5	59.8	59.6
29	Branch, Mich........................	....	....	58.3	....	58.3
30	Lenawee, Mich.......................	....	....	61.1	60.8	60.9
Average................................		61.28	58.02	59.60	59.25	....

*Prime numbers refer to number of varieties included in average when fewer than the complete set of 10 varieties were grown.

Table 16 gives the average test weight for each of the locations during the entire period. Comparison of the results from Locations 1 to 4 indicates that heavy soils tend to produce an increase in weight per bushel, although the data in Table 10 are rather inconclusive in this respect. However, climate undoubtedly has much more effect on test weight than does soil.

The relationship between test weight and protein content is interesting. It appears as though the protein content may increase with both increasing and decreasing test weight. With plump grain the test weight will increase as the spaces between the starch grains are filled by more and more protein material; on the other hand, with shrunken grain the protein content increases as the test weight decreases due to an increase in the relative proportion of protein to carbohydrate materials in the wheat berry.

Table 17 indicates the fact that varieties differ materially in test weight. The white variety (American Banner) almost invariably had a lower test weight than the red varieties in the series. This is a low-protein variety. Nabob, on the other hand, has the highest test weight and is also a low-protein variety. Michigan Amber has a fairly low test weight and is second highest in amount of protein. Many possible combinations are found. Test weight may be affected by the heredity of the variety; for example, Trumbull and Fulhio are both selections from Fultz, and all three varieties had the same average test weight for the 4-year period.

YIELD PER ACRE AND QUALITY

To the farmer, yield per acre is the most important factor of quality. Unless a variety is high yielding it will not be grown. A high yielding variety is, under our present marketing conditions, likely to be grown even if the quality for the miller and the baker is not as good as it should be. By introducing high yielding varieties which also possess the desired strength, the plant breeder offers the most satisfactory method for crowding unwanted varieties off the market. A high yielding variety is frequently found to have considerable resistance to disease and at least moderate ability to survive the winters. Unless a variety possesses these desirable characteristics, its average yield usually drops and it is automatically eliminated.

Tables 18 and 19 give the yields averaged according to locations and by varieties, respectively. Nabob has proven the heaviest yielder over the period. However, this variety has proven rather undesirable in several other respects. Fulhio has satisfactory quality and yields almost as much as Nabob. Both Trumbull and Fulhio outyield their common ancestor, Fultz. Michigan Amber and Kharkov are, with Fultz, the three lowest yielding sorts.

Consideration of yield per acre shows that it has some bearing upon the strength of the wheat produced. A given soil at any particular time or season has only a certain amount of soil nutrients available for use by the growing plant. The available nitrate supply in the soil is probably the most important single factor determining amount of protein and strength of the wheat produced. The carbohydrate portions of the wheat berry, being produced by photosynthesis, are not limited by those factors governing the pro-

TABLE 17.—Test Weight per Bushel for Different Varieties

(Tri-State plantings—1930-1933)

Year	Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Av.	Samples
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*No.*
1930	61.4	61.6	61.5	61.1	59.8	61.6	....	61.3	62.1	61.4	....	61.3	180
1931	58.3	58.3	58.3	58.1	56.5	58.7	....	57.8	58.1	57.9	58.0	58.0	230
1932	59.7	60.2	59.8	59.7	58.3	....	60.0	59.5	59.7	59.7	59.3	59.6	230
1933	58.9	59.6	59.1	59.0	58.1	....	59.7	59.2	59.8	59.6	59.4	59.2	224
Average	59.6	59.9	59.6	59.4	58.1	60.1	59.8	59.4	59.7	59.6	58.9	59.4	....
No. of tests	90	89	90	90	89	44	45	88	83	88	68	....	864
Test weight ranking (Bald Rock and Berkeley Rock excluded)													
1930	4	2	3	8	9	....	....	7	1	4	6*	....	....
1931	1	1	1	4	9	....	....	8	4	7	6	....	....
1932	3	1	2	3	9	....	....	7	3	3	8	....	....
1933	8	2	6	7	9	....	....	5	1	2	4	....	....
Av. (test weight)	3	1	3	6	9	....	....	6	2	3	8	....	....
Av. (per cent protein)	1	7	3	4	9	....	....	2	5	6	7	....	....

*Estimated.

duction of raw materials in the soil which are required in protein formation. With a long growing period, starch elaboration will continue even after the supply of soil nitrates has been largely exhausted, thus producing starchy, low-protein wheat. A soil in low fertility with a relatively small supply of available nitrates may give a good yield per acre, but the higher the yield the lower will be the percentage of protein in the grain, as the increased yield consists largely of additional starchy material. With a limited supply of soil nitrates, it may therefore be expected that there will be a tendency toward the production of lower protein wheat with increasing yield per acre, whether this increased yield is due to heavier yielding varieties or to seasonal conditions favoring high carbohydrate production. Differences in root systems due to variety undoubtedly have an influence as well. Fertilizer applications also affect both yield and percentage of crude protein in the wheat, but this phase will be considered later in the section (Page 38) dealing with "Effect of Fertilizers".

TABLE 18.—Average Yield per Acre for 10 Varieties*

(Tri-State plantings—1930-1933)

No.	Location, County	1930	1931	1932	1933	Average	Samples
		Bu.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*No.*
1	Fulton, Ohio	15.2^{9}	13.4	10 9	20.4	15.0	39
2	Fulton, Ohio	39.0^{9}	22.9	35.2	24.8	30.2	39
3	Fulton, Ohio	28.9^{9}	...	35.5	22.9	29.1	29
4	Fulton, Ohio	41.5^{9}	40.7	33.6	30.0	36.3	39
5	Fulton, Ohio	...	40.2	28.0	26.7	31.6	30
6	Henry, Ohio	...	34.4	32.3	27.5†	33.3	20
7	Trumbull, Ohio	23.2^{9}	...	...	...	23.2	9
8	Mahoning, Ohio	22.2^{9}	36.0	29.5	36.1^{4}	30.3	33
9	Wayne, Ohio	37.2^{9}	45.3	25.6	44.8	38.2	39
10	Knox, Ohio	34.1^{9}	32.4	28.6	31.8	31.7	39
11	Franklin, Ohio	21.8^{9}	37.5	19.7	29.9	27.4	39
12	Miami, Ohio	18.4^{9}	30.2	39.2	40.6	32.4	39
13	Hamilton, Ohio	28.7^{9}	...	28.7	36.6	31.4	29
14	Meigs, Ohio	31.8^{9}	39.8	26.5	30.0	32.0	39
15	Belmont, Ohio	...	31.1	22.0	25.0	26.0	30
16	Jennings, Ind.	18.0^{9}	19.6	15.3^{9}	13.8^{9}	16.7	37
17	Lawrence, Ind.	16.9^{9}	38.9	19.0	23.1	24.7	39
18	Tippecanoe, Ind.	26.6^{9}	43.2	29.1	33.0	33.1	39
19	Kalamazoo, Mich.	28.6^{8}	27.7^{8}	...	24.2	26.6	26
20	Ingham, Mich.	40.4^{7}	35.9	43.1	28.2	36.6	37
21	Missaukee, Mich.	33.2^{8}	31.1	33.3	27.1	31.1	38
22	Branch, Mich.	31.1^{8}	...	...	...	31.1	8
23	Branch, Mich.	23.0^{8}	...	...	...	23.0	8
24	Ingham, Mich.	35.3^{6}	...	...	...	35.3	6
25	Clinton, Mich.	...	33.8	...	...	33.8	10
26	Ionia, Mich.	...	19.7	...	...	19.7	10
27	Monroe, Mich.	...	32.2	38.2	24.6	31.7	30
28	Sanilac, Mich.	...	...	28.1	26.5^{9}	27.3	19
29	Branch, Mich.	...	...	29.6	...	29.6	10
30	Lenawee, Mich.	...	...	51.8	29.8	40.8	20
	No. of samples	180	208	229	212	...	829
	Average	28.1	32.7	29.7	28.5	29.8	...

*Prime numbers refer to number of varieties included in average when fewer than the complete set of 10 varieties were grown.

†Not included in average (estimate only).

TABLE 19.—Average Yield in Bushels per Acre for Various Varieties
(Tri-State plantings—1930-1933)

Year	Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Samples	Average
	Bu.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*No.*	*Bu.*
1930....................	28.7	30.4	29.3	28.5	27.5	27.2	....	28.1	23.5	28.1	....	180	28.06
1931....................	33.7	33.8	33.6	34.7	32.4	31.8	....	31.2	31.2	30.6	34.1	208	32.72
1932....................	29.7	30.2	30.4	30.5	31.5	....	30.8	28.4	28.3	28.0	29.9	229	29.75
1933....................	30.4	31.3	31.2	27.0	26.5	....	27.0	27.1	28.1	27.4	28.5	212	28.52
Average...........	30.60	31.40	31.13	30.15	29.51	29.53*	28.99*	28.65	28.23	28.55	30.75†	....	29.82
No. of tests........	87	86	85	87	86	42	44	84	80	84	64	829	....

*2-year average.
†3-year average.

GENERAL CONCLUSIONS AND THE ZONATION PROGRAM

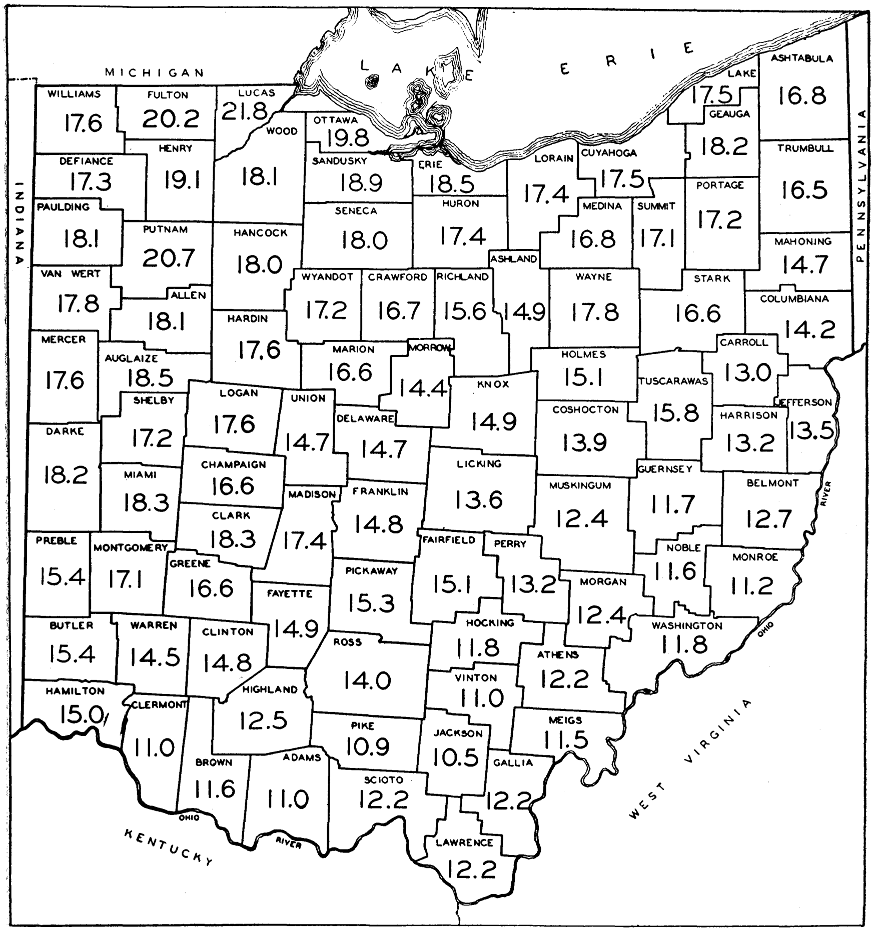
The main object of the program commenced in 1929 was the elimination of undesirable varieties and the fostering of desirable varieties in sections of the Tri-State Territory to which they were best adapted, so that the desired quality and quantity of the crop might be obtained with maximum benefit to the grower, miller, and ultimate consumer.

From 4 years' experience with the varieties in the quality series, the following general conclusions have been drawn:

1. Precipitation (rainfall) has an important role in lowering the protein content of wheat when it falls just preceding or during heading time.
2. High temperature during the last 2 to 3 weeks before harvesting tends to decrease the weight per bushel.
3. Protein content in wheat increases as the soil becomes heavier in texture and also as the relative fertility of the soil increases.
4. Some varieties possess superior protein qualities when compared with others. They also differ in their abilities to produce large or small amounts of protein.
5. Amount of protein is the most important factor governing strength of wheat in varieties liberated under modern methods of plant breeding, under which all inferior quality (of protein) varieties are withheld from general distribution.

Man has no method for regulating the climate; therefore, the strength and quality of wheat will always vary from season to season. However, many of the wider extremes in strength can be levelled out by correct farm practices and by growing the most desirable varieties. For wheat production there normally is sufficient precipitation and frequently an excess in the Tri-State area. However, on well drained sandy soils this moisture is less effective than on the heavier soils which are normally more poorly drained and more retentive of moisture. Soil, therefore, modifies the effect of rainfall insofar as wheat is concerned. Temperature produces its greatest influence on wheat strength chiefly by indirect means. By warming the soil it accelerates nitrate production, and by alternate freezing and thawing in the spring it reduces the wheat stand through soil heaving. This heaving is probably the reason for most of the acreage abandoned in the spring, although in some cases the wheat is actually killed by extremes of low temperature.

Topography of the soil affects drainage, as does the material from which the soil was produced. Generally speaking, the limestone soils of Ohio are not so well drained as those originating from sandstone and shale materials. Age of the soil and the length of time it has been exposed to the leaching action of the weather have a large influence on the native fertility of the soil, and fertility of the soil has a large influence on wheat strength. It is estimated that the soils of the Illinoian Drift (e. g., Clermont) are about 300,000 years old. They are now acid and are free from carbonates to a depth of from 8 to 10 feet. Probably, the Clermont is naturally one of the poorest soils in the State. The Wisconsin Drift soils are younger, having been laid down much later than the Illinoian. The Early Wisconsin Drift soils (e. g., Russell) are leached free of carbonates to a depth of about 40 to 60 inches while the Late Wisconsin Drift soils (e. g., Miami) have been leached still less (to about 24 to 30 inches). The glacial lacustrine soils are the youngest of the glacial soils and frequently are slightly alkaline or neutral in reaction at the surface. These lacustrine soils are probably the highest of any in terms of natural fertility. When not too heavy and when adequately drained, they produce excellent yields of wheat. Lamb (32) has shown that some of the counties in northwestern Ohio (lacustrine soil area) produce the highest average yields in the State. The map shown as Figure 3 is taken from the publication by Lamb (32) and illustrates the point.



(Taken from Ohio Experiment Station Bulletin 507)

Fig. 3.—Average yield per acre of wheat in Ohio, by counties, 1920-1929

Large areas of Indiana and Michigan consist of soils of the same general characteristics as those in Ohio. Soil differences, therefore, seem to offer a good basis for zoning the three states. It has already been shown that wheat strength is very largely influenced by texture and by fertility of the soil (see Tables 10 and 11). Accordingly, the soils of the three states have been grouped together, using a geological and textural basis. A Generalized Soil

Map[3] for Southern Michigan, Indiana, and Ohio was drawn to serve as a basis for zoning the area for expected wheat strength. Naturally, considering the size of the territory covered by the map, the various areas represent only the predominant soil types present. Thus, areas of heavy soils are to be found in the sections described as sandy, or sandy areas exist in areas described as heavy in texture.

In the following descriptions the numbers correspond to those given on the soil map.

Legend for Tri-State Soil Map

1. Principally glacial sands and sandy loams underlain by several feet of sand. Mainly level plains, acid, low in organic matter, low in moisture, and low in fertility. Soils principally Plainfield and Ottawa types.

2. Principally glacial sandy loams and sands of medium to low fertility. Normally well-drained with hilly to level topography. Area varies from acid soils deficient in limestone to those strong in limestone. Soils mainly of Roselawn, Coloma, Emmet, Rubicon, and Mancelona Series.

3. Principally glacial sandy loams and sand of medium to low fertility, generally acid in surface layers. Fifteen to 20 per cent of area composed of peats and mucks. There are some small associated areas of clay soils included. Soils are very variable; mainly Hillsdale, Bellefontaine, Coloma, Fox, Plainfield, Miami, and Conover Series.

4. Principally sands and sandy loams of lacustrine origin, ranging from acid to alkaline, from high to low fertility, from good to poor drainage. Some small areas of heavy soils are included. Topography generally level but some low ridges present. Light colored soils, Plainfield and Berrien; dark colored soils, Newton, Wauseon, and Maumee.

5. Principally glacial loams and sandy loams, medium to high fertility. Topography, gently rolling to nearly level with small hilly areas. Some small swamp areas included. From 30 to 40 per cent of area is intermixed with medium fertile sands and sandy loams. About 15 to 20 per cent of area composed of muck and peat. Light colored soils, Bellefontaine (gravelly subsoil) and Miami; dark colored soil, Brookston.

5A. Principally glacial and lacustrine loams and sandy loams underlain by clay, medium to high fertility. Usually high in lime, in part stony, and from level to hilly in topography. Due to its northern location, not much wheat is grown on these soils.

6. Principally clays, clay loams, and silt loams underlain by clay of glacial and of lacustrine origin. High in lime, relatively high in organic matter and nitrogen, relatively fertile. Some small areas of poorer and sandier soils. Topography generally level or smooth, some low swells and narrow ridges. About 5 per cent muck and peat. Area naturally poorly drained. Dark colored soils, Brookston clay, Toledo silty clay; light colored soils, Nappanee and Fulton silty clay loam.

7. Principally glacial prairie land, largely silt loam of high average fertility. Mostly well drained, ranging from moderately acid to sweet. Similar to extensive dark soil areas in Illinois. Gently rolling areas consist of Carrington; level land, probably Webster; lowest land, Clyde.

8. Principally glacial silt loams of good fertility (Late Wisconsin Drift derived from limestone). Topography gently undulating. Fair drainage and somewhat acid. Light colored soils, Bellefontaine, Miami, and Crosby; dark colored, Brookston and Clyde.

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[3]The map was prepared in cooperation with G. W. Conrey, Chief, Ohio Soil Survey, and was originally published in tentative form in the Second Annual Report of the Tri-State Soft Wheat Improvement Association (45). Information was also obtained from J. O. Veatch (29), Michigan State College, East Lansing, Michigan, and from T. M. Bushnell (18), Purdue University, Lafayette, Indiana. The author wishes to acknowledge his indebtedness to these members of the respective state soil departments for their help and constructive criticisms. Valuable information was also obtained from various United States Department of Agriculture county soil survey reports and from the geological studies of Leverett (34).

9. Principally glacial silty clay loams of Late Wisconsin Drift derived from limestone. Topography and general soil characters similar to Group 8. Drainage poorer. Light colored soils, Miami and Crosby; dark colored, Brookston and Clyde.

10. Principally silt loams of the Early Wisconsin Drift derived from limestone. Less dark soils and soils generally more acid and less fertile than in Area 8. Light colored soil, Russell; dark colored, Brookston.

11. Principally silt loams of Illinoian Drift. Soils very acid and less fertile than in Area 10. Drainage naturally poor. Light colored soils, Cincinnati, Rossmoyne, and Clermont; very limited amount of dark soils (Blanchester).

11A. Soils of same type and origin as Area 11. Soils somewhat less fertile and poorer in drainage conditions than in Area 11. Light colored soils, Vigo, Gibson, and Cincinnati; dark soil, Cory (limited amount).

12. Principally silt loams of Illinoian Drift, also soils of loessial origin. Area mixed insofar as soils are concerned. Area probably slightly more fertile and better drained than in Area 11 and 11A. Considerable areas of more fertile darker soils in river valleys. Principal soils, Princeton (brown), Owensville (brownish yellow), and Alford (grayish brown).

13. Principally silt loams of the glaciated sandstone and shale region with porous subsoils (Late Wisconsin Drift). Soils moderately fertile, acid. Topography undulating to rolling. Light colored soils, Wooster, Canfield, Volusia, and Trumbull; dark soils, Chippewa.

13A. Soils of similar origin to Area 13. Loams and sandy loams dominant soil texture.

14. Principally silt loams and silty clay loams of the glaciated sandstone and shale region (Late Wisconsin Drift). Very heavy, impervious subsoils, difficult to drain by tiling. Topography undulating to very gently rolling. More acid than 13. Light colored soils, Ellsworth, Mahoning, and Trumbull; dark colored soil, Chippewa.

15. Principally silt loams residual (non-glaciated) from sandstone and shale. Rolling to very rolling topography with good drainage. Some erosion on steeper slopes. Soils are acid and moderately fertile. Much waste land. Predominant light colored soil, Muskingum and Zanesville. In Indiana the Zanesville soil is the principal cultivated soil in Area 15.

16. Principally silt loams residual (non-glaciated) from limestone. Soils are acid, with limestone about 5 to 10 feet below the surface. Much waste land in area. Topography gently rolling to rolling. Light colored soils, Hagerstown, Frederick, and Bedford.

SOME USES FOR THE SOIL MAP

The generalized soil map may prove useful to purchasers of wheat and to others interested in wheat quality. For intensive investigations in any section it will be advisable to refer to a larger scale map giving greater detail than that shown on this generalized map. The following points refer only to average conditions and are of a very general nature:

Sandy soils.—These soils normally may be expected to produce weak wheats, particularly when the yields are above average. When moisture is deficient, the yields will be low and low test wheat may result from shrivelling of the grain. Protein content will be high under these conditions. There is some indication that the weak, soft white variety, American Banner, will do relatively better in yield than the red varieties on sandy soils.

Loams.—These soils are intermediate in character. Their higher fertility as compared to sandier soils will be offset by their greater productivity, and medium to low protein wheat should result.

Silt loams.—These are good productive wheat soils. Provided they are well drained, medium amounts of protein will result. In sections where abandonment losses are heavy, a considerable admixture of wheats of the hard winter type may be obtained. These harder wheats will increase the general level in protein content. In Central Indiana considerable Purkof and Michikof may be expected. With high yields the tendency will be toward a reduction in protein. On the low-fertility silt loams, low yields will give a normal protein wheat; whereas with high yields a low-protein wheat may be expected.

Clay loams and clays.—These soils are naturally poorly drained but in drier years will produce high yields of satisfactory strength. When abandonment is high a higher protein may be expected, particularly if conditions are warm and dry, thus favoring nitrate production in the soil. Some admixture of hard winter wheat type may be expected. In Northwestern Ohio and to a lesser extent in Northeastern Indiana some hard spring wheat is also produced on these soils and may become mixed in with the general run of the crop in some instances. The indifferent quality of these spring wheats makes it difficult to find a place for them in milling.

The map also indicates areas most urgently in need of more winter-resistant varieties (heavier soil areas). The problem of winter resistance is further complicated by the variable amount of protection provided by snow cover which becomes progressively less toward the south. There appears to be an east to west section through Ohio and Indiana at about the latitude of Columbus, Ohio, which suffers heavily through lack of winter protection due to deficient snow cover.

EFFECT OF FERTILIZERS

During the 5-year period, various samples have become available from time to time which appeared suitable for giving information that might aid in explaining some of the differences in strength and general crop quality obtained from soils known to differ in general fertility. These samples have all been collected in Ohio and were grown principally on various plots at Wooster; some, however, were farmer-grown material.

The various samples were not all grown in any one year. As an estimate of strength the samples will be considered principally in regard to their protein contents, because the baking procedures were not uniform during the various seasons under review. The baking methods employed were the same as those already outlined for the "Preliminary Survey, 1929" and the "Quality Series, 1930-1933".

TOP-DRESSING WHEAT EXPERIMENTS

RESPONSE TO NITROGEN IN THE 1930 CROP

In order to demonstrate whether any relationship existed between wheat strength and fertilizer treatment applied to the growing crop, various samples were collected from plots grown at Wooster. Part of these samples were from wheat plots receiving a top-dressing application of nitrogen fertilizer at different times of the year or during different stages of development in the life history of the plant.

Part of the experiment was designed to test the effect of nitrogen when applied in different carriers. The three varieties Michikof, Fulhio, and American Banner were used. In this series of 1930 crop samples (Table 20) com-

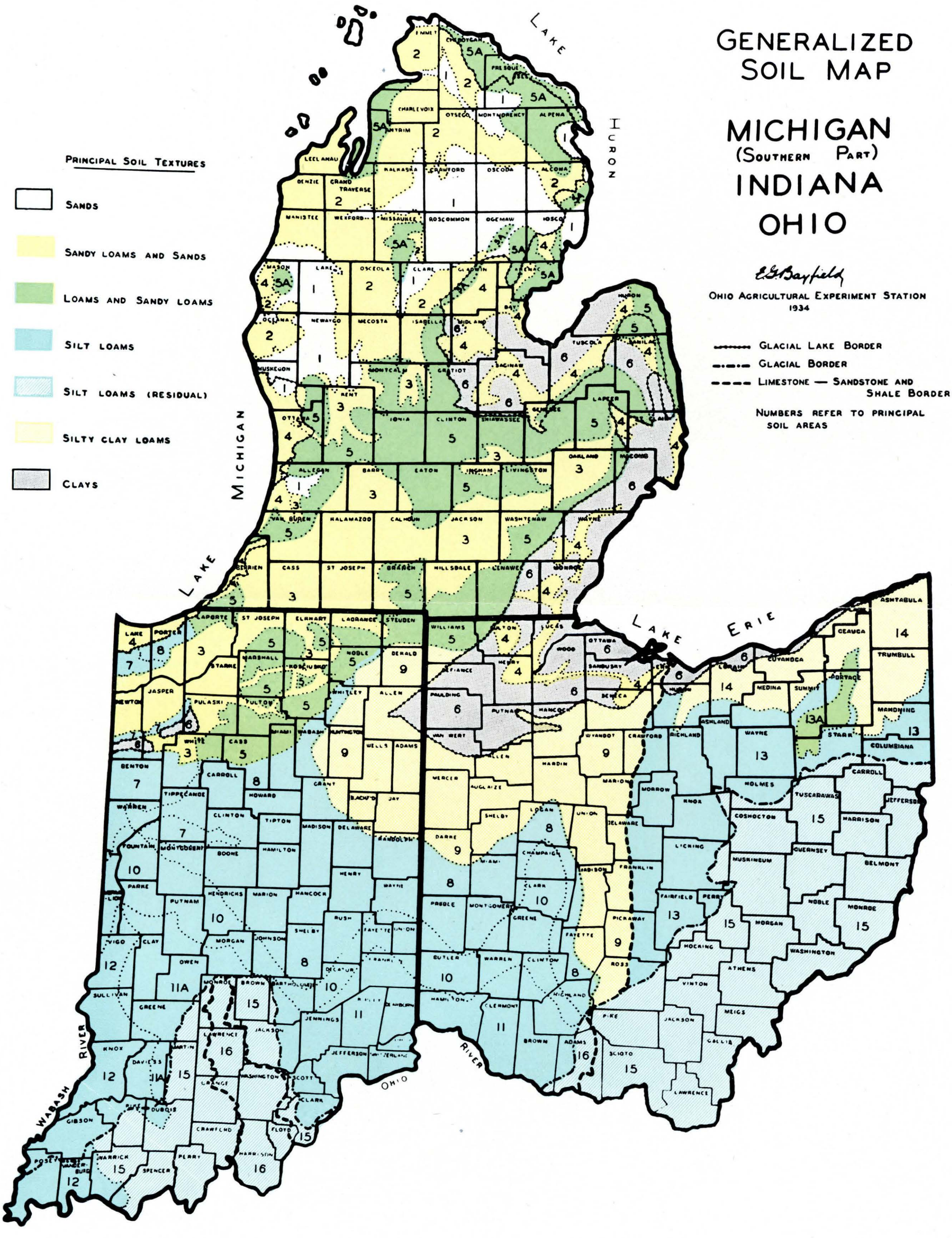
GENERALIZED SOIL MAP
MICHIGAN (SOUTHERN PART)
INDIANA
OHIO
E. G. Bayfield
OHIO AGRICULTURAL EXPERIMENT STATION
1934
PRINCIPAL SOIL TEXTURES
SANDS
SANDY LOAMS AND SANDS
LOAMS AND SANDY LOAMS
SILT LOAMS
SILT LOAMS (RESIDUAL)
SILTY CLAY LOAMS
CLAYS
GLACIAL LAKE BORDER
GLACIAL BORDER
LIMESTONE — SANDSTONE AND SHALE BORDER
NUMBERS REFER TO PRINCIPAL SOIL AREAS
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
OHIO RIVER
WABASH RIVER

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TABLE 20.—Effect of Various Nitrogen Carriers Upon Wheat at Wooster, 1930

Fertilizer applied*	Nitrogen applied	Sample	Variety	Yield per acre	Test weight	Wheat protein	Increase†	Flour protein	Flour ash	Absorption	Loaf volume	Grain	Texture	Color score
	Lb.	*No.*		*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Cc.*			
Nitrate of soda, at heading	32.50	828	Michikof	28.9	62.2	15.5	4.9	14.7	0.522	64.2	2140	96	96	95
Nitrate of soda, at heading		839	Fulhio	32.8	62.5	14.9	4.7	13.8	.513	52.9	1985	96	95	94
Calnitro, at heading		830	Michikof	25.8	62.7	14.3	3.7	13.3	.497	63.2	2060	96	97	95
Calnitro, at heading	32.50	831	Fulhio	31.7	62.4	13.7	3.5	12.1	.486	52.5	1875	96	97	95
Calnitro, at heading		829	American Banner	27.5	61.2	12.3	3.0	11.2	.439	52.5	1970	94	94	95
Urea, at heading		836	Michikof	29.2	62.8	12.6	2.0	12.0	.536	63.1	1990	95	95	94
Urea, at heading	32.50	837	Fulhio	38.1	62.7	12.4	2.2	10.6	.427	53.5	1880	97	97	96
Urea, at heading		835	American Banner	29.7	61.3	11.1	1.8	9.8	.456	51.9	1810	92	92	92
Sulfate of ammonia, at heading		833	Michikof	31.7	63.0	12.2	1.6	11.5	.486	59.5	1970	96	97	96
Sulfate of ammonia, at heading	32.50	834	Fulhio	35.6	63.0	12.0	1.8	10.6	.450	51.9	1895	97	97	97
Sulfate of ammonia, at heading		832	American Banner	26.1	60.6	10.7	1.4	9.3	.445	51.1	1800	93	92	94
Check—not top-dressed	....	840	Michikof	29.4	62.5	10.6	....	10.2	.517	59.5	1835	97	96	94
Check—not top-dressed	....	844	Fulhio	28.6	61.8	10.2	....	9.0	.457	51.8	1825	95	95	95
Check—not top-dressed	....	838	American Banner	31.4	60.6	9.3	....	7.9	.441	49.6	1780	94	94	94
Average—top-dressed plots	....	....	....	30.6	62.2	12.9	2.9	11.7	.477	56.0	1943	95.3	95.4	94.8
Average—all checks	....	....	....	29.8	61.6	10.0	....	9.0	.472	53.6	1813	95.3	95.0	94.3

*All plots received basic treatment of 320 pounds 2-14-4 fertilizer at seeding time.
†Percentage wheat protein increase due to treatment.

parisons of results obtained from the various carriers of nitrogen may be made with those from an untreated check plot. The different carriers were applied at heading time, equivalent amounts of nitrogen (32.5 pounds) being used in each case. The check plots, as well as the plots top-dressed at heading time, received a uniform basic application of 300 pounds of 2-14-4 fertilizer at time of seeding. Table 20 gives the data.

A second series of samples (Table 21) consisting of one variety, Fulhio, was also collected. These samples received treatments consisting of one nitrogen carrier only (nitrate of soda), the top-dressing being applied at different times and rates. These 1930 crop samples indicate that heading-time applications increase wheat protein more than the same quantity of nitrogen when applied earlier in the life of the plant. Thus, 600 pounds of nitrate of soda (97.5 pounds of nitrogen) applied March 15 gave a smaller increase in protein than 200 pounds applied at heading time. The late fall application proved the least efficient insofar as protein increases were concerned. It also gave smaller increases in yield per acre than the spring applications. Heading-time applications did not benefit yield per acre materially. Sample 841 which received both phosphoric acid and potash, as well as nitrogen, gave some increase in yield over nitrogen alone. This plot also gave heavier test weight and higher protein wheat, possibly due to a superior balance in nutrients supplied in the top-dressing.

All nitrogen carriers when applied at heading time are not equally efficient for increasing protein in the resulting crop (Table 20). Nitrogen in the nitrate forms (nitrate of soda and Calnitro) gave higher protein increases than nitrogen in the ammonium form (sulfate of ammonia). Nitrogen in the organic form (urea) also gave somewhat higher protein wheat than in the ammonium form.

Varieties do not all respond in the same way to available nitrogen supplies. The weak white variety American Banner in comparable treatments with all carriers produced less protein than the hard vitreous red variety Michikof. The protein increases with Fulhio (medium strength soft red winter) were more erratic, but in all cases this variety gave more protein than American Banner.

These plot-grown samples indicate that the small top-dressing, spring applications of nitrogen frequently used by farmers should not materially raise the protein content of the resulting crop in a normal season.

SAMPLES GROWN BY FARMERS, 1929 AND 1930

To study the effect of the light spring applications used in agricultural practice for top-dressing wheat, a number of samples were received through the courtesy of Mr. Earl Jones, Extension Agronomist of the Ohio State University, Columbus. Table 22 gives pertinent data on the 10 pairs of samples received in each of the 2 years. Each pair of samples originated from a grower's field, part of which was top-dressed. It will be observed that, on the average, the increases in protein were small in both years. While the yields per acre are not available in detail for 1929, top-dressing in that year gave as good increases in yield as in 1930. It appears that most of the nitrogen added as top-dressing in the early spring is used up in additional vegetative growth and yield. In some cases this additional growth apparently produces a shortage of protein-forming materials at filling time, and the crop from the treated

TABLE 21.—Effect of Several Top-dressing Methods Upon Fulhio Wheat at Wooster, 1930

Fertilizer applied*	Nitrogen applied	Sample	Yield per acre	Test weight	Wheat protein	Increase†	Flour protein	Flour ash	Absorption	Loaf volume	Grain	Texture	Color score
	Lb.	*No.*	*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Cc.*			
Nitrate of soda, at heading	32.50	847	27.8	60.4	13.2	3.0	12.1	0.446	55.6	2060	94	94	94
Nitrate of soda, at heading	As No. 847 + 390 lb. 0-16-0 and 63 lb. muriate of potash	841	35.3	62.0	14.4	4.2	13.3	.521	52.5	1970	96	95	95
Nitrate of soda, March 15	97.50	846	46.4	60.3	12.6	2.4	11.7	.438	54.9	1905	91	91	91
Nitrate of soda, March 15	48.75	845	40.6	61.4	11.8	1.6	10.7	.449	50.6	1940	94	94	94
Nitrate of soda, March 15	16.25	843	37.2	61.7	10.5	0.3	9.4	.443	52.3	1840	95	95	95
Nitrate of soda, April 15	32.50	848	36.9	62.5	10.5	0.3	9.3	.447	54.8	1930	95	95	96
Nitrate of soda, in late fall	32.50	842	33.1	61.9	10.3	0.1	9.1	.444	50.6	1870	96	95	95
Check, not top-dressed	None	844	28.6	61.8	10.2	....	9.0	.457	51.8	1825	95	95	95
Av. top-dressed at heading time	....	....	31.5	61.2	13.8	3.6	12.7	.483	54.1	2015	95.0	94.5	94.5
Av. top-dressed in spring	....	....	40.2	61.5	11.3	1.1	10.3	.444	53.2	1904	93.7	93.7	94.0

*All plots received basic application of 320 pounds 2-14-4 fertilizer at seeding time.
†Increase in percentage of wheat protein over check plot.

TABLE 22.—Effect of Top-dressing Wheat in Various Sections of Ohio, 1929 and 1930

Spring fertilizer application	Variety	County source	Yield per acre		Test weight		Wheat protein			Loaf volume	
			Not top-dressed	Top-dressed	Not top-dressed	Top-dressed	Not top-dressed	Top-dressed	Increase*	Not top-dressed	Top-dressed
Lb.			Bu.	Bu.	Lb.	Lb.	Pct.	Pct.	Pct.	Pct.	Pct.
1929 Crop Samples											
101 Calnitro	Trumbull	Marion	....	....	57.2	56.6	9.02	9.90	+0.88	1770	1830
103 Calnitro	Trumbull	Marion	....	....	57.8	57.8	8.09	8.24	+0.15	1720	1700
120 Calnitro	Trumbull	Wyandot	....	....	58.5	56.2	10.19	10.26	+0.07	1740	1720
120 Calnitro	Trumbull	Seneca	....	....	56.1	57.4	8.22	9.44	+1.22	1560	1630
200 Calnitro	Trumbull	Pickaway	....	....	56.7	57.0	7.80	8.56	+0.76	1680	1740
Top-dressed, amount unknown	Trumbull	Stark	....	....	58.2	57.6	10.28	9.96	—0.32	1820	1730
140 Calnitro	Fulhio	Licking	....	....	56.4	56.9	7.99	8.02	+0.03	1630	1560
150 Calnitro	Fulhio	Wayne	....	....	57.4	56.8	8.18	8.36	+0.18	1600	1730
150 nitrate of soda	Fulhio	Wayne	....	....	55.5	55.5	9.73	9.77	+0.04	1860	1800
156 nitrate of soda	Not named	Fairfield	....	....	57.6	57.6	8.00	7.91	—0.09	1630	1640
Av. for 1929 samples	....	....	....	....	57.1	56.9	8.75	9.04	+0.69	1701	1708
1930 Crop Samples											
105 Calnitro	Trumbull	Marion	12.0	18.1	60.4	59.4	10.52	10.22	—0.30	1955	1880
113 Calnitro	Trumbull	Marion	22.0	31.2	61.2	61.2	10.38	10.47	+0.09	1870	1850
117 Calnitro	Trumbull	Shelby	24.2	28.8	62.2	61.9	10.99	10.46	—0.53	1970	1885
100 nitrate of soda	Trumbull	Trumbull	....	....	62.5	61.6	11.08	11.39	+0.31	1970	1890
143 Calnitro	Fulhio	Wayne	12.3	20.6	60.2	61.5	11.79	10.97	—0.82	1860	1760
150 Calnitro	Fulhio	Licking	9.6	17.9	62.7	62.6	11.15	11.22	+0.07	1930	1890
152 Calnitro	Fulhio	Licking	21.3	27.1	62.3	64.0	9.62	10.71	+1.09	1945	1855
115 Calnitro	Fulhio	Wayne	17.6	18.1	62.5	62.3	11.00	10.47	—0.53	1900	1885
146 Calnitro	Poole	Coshocton	23.1	20.2	60.1	61.1	9.61	9.43	—0.18	1945	1885
106 Calnitro	Dawson	Wyandot	14.6	22.9	58.4	59.8	8.69	9.97	+1.28	1695	1630
Av. for 1930 samples	....	....	17.4	22.8	61.2	61.5	10.48	10.53	+0.05	1904	1841

*Increase in percentage wheat protein due to top-dressing.

plots is lower in protein than from the untreated and lower yielding sections of the field. Other fields produce the opposite result, probably due to having soils with stronger nitrifying powers.

No entirely satisfactory explanation is available for the consistently poorer baking results from the top-dressed 1930 plots. The top-dressed plots gave wheat with flour proteins slightly lower (0.04 per cent) and ash contents slightly higher than those of wheats from the untreated plots. The differences are too small, however, to account for differences in baking results (average 63.0 cubic centimeters).

RESPONSE IN 1931 CROP AT WOOSTER

In 1931 two series of samples were collected from various top-dressed plots at Wooster. The same varieties were included as in the 1930 Wooster samples; however, most of the 1931 samples did not receive the same treatments as those included in the 1930 study. Therefore, direct comparisons in most cases are not possible. The 1931 season was rather unfortunate for this particular experiment, due to the fact that an unusually large supply of soil nitrates was available for the crop. As a result, relatively small differences resulted from the top-dressings.

The samples from plots top-dressed at heading time (Table 23) show the same trends as these varieties did in 1930. American Banner gave smaller protein increases than either Fulhio or Michikof. Michikof gave the largest protein increases, with Fulhio occupying an intermediate position. The season also showed that Michikof was unable to use the favorable growing conditions to as good advantage as the other varieties. Lamb and Salter (33) have observed this characteristic in Michikof.

From Table 24 a few comparisons may be made regarding nitrogen carriers and protein production. Nitrogen in the ammonium form (sulfate of ammonia) again produced less protein than the same amount of nitrogen in the nitrate form (either as Calnitro or nitrate of soda). Urea-treated plots gave a slightly higher percentage protein in the crop than the sulfate. The mixed fertilizer top-dressing treatments all gave somewhat higher protein wheat than the equivalent amount of nitrogen as either nitrate of soda or sulfate of ammonia. The same trend was pointed out in discussing the 1930 samples.

The differences found in the 1931 samples are too small to be significant if it were not for the fact that these small differences rather uniformly confirm the results obtained on the 1930 samples, which gave relatively large differences.

RESPONSE IN WOOSTER-GROWN 1933 SAMPLES

A limited series of samples was available from the 1933 crop. These samples contained no examples of plots top-dressed at heading. All treated plots were top-dressed on April 15. Yields per acre were high and the increases from top-dressing were rather small although somewhat more favorable than in 1931. Table 25 indicates that top-dressing increased both yield per acre and per cent protein in the wheat. With one exception (No. 2197), all top-dressed plots gave lower test weights than the check plots. In fact, there seems to be a decided tendency for top-dressing to decrease the test weight as the majority of the samples from such plots (excepting Table 20 and farmers' samples for 1930) have given lower test weights than their respective check plots. In years when the average test weight is near the borderline between two Federal Market Grades, the practice of top-dressing may cause some monetary loss to the grower through reduction in grade.

TABLE 23.—Effect of Top-dressing Three Varieties in the Spring and at Heading Time at Wooster, 1931

Fertilizer applied*	Nitrogen applied	Sample	Variety	Yield per acre	Test weight	Wheat protein	Increase†	Flour protein	Flour ash	Absorption	Loaf volume	Grain	Texture	Color score
	Lb.	*No.*		*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Cc.*			
Nitrate of soda, at heading		1083	Michikof	39.2	56.4	14.5	1.3	13.6	0.535	59.5	580	98	98	98
Nitrate of soda, at heading	32.50	1079	Fulhio	55.1	57.2	13.2	1.1	11.7	.462	54.1	490	97	98	98
Nitrate of soda, at heading		1075	American Banner	51.1	55.5	12.0	0.9	10.6	.429	52.5	475	96	96	97
Av. 32.50 lb. N as nitrate of soda at heading	....	Av.	Three varieties	48.5	56.4	13.2	1.1	12.0	.475	55.4	515	97	97	98
Nitrate of soda, April 15, and again at heading		1084	Michikof	37.8	56.8	14.2	1.0	13.3	.527	57.1	602	99	99	98
	16.25	1080	Fulhio	55.3	56.1	13.3	1.2	11.7	.433	53.2	507	98	97	98
		1076	American Banner	49.6	56.5	11.8	0.7	10.3	.423	55.3	440	94	96	96
Av. 32.50 lb. N as nitrate of soda, split application	....	Av.	Three varieties	47.6	56.5	13.1	1.0	11.8	.461	55.2	516	97	97	97
Nitrate of soda, April 15		1085	Michikof	37.6	56.0	14.6	1.4	13.9	.518	56.3	562	99	99	98
Nitrate of soda, April 15	32.50	1081	Fulhio	50.8	55.8	13.1	1.0	11.9	.433	53.4	447	97	96	96
Nitrate of soda, April 15		1077	American Banner	47.0	55.0	11.5	0.4	9.9	.457	53.8	460	97	96	97
Av. 32.50 lb. N as nitrate of soda, April 15	....	Av.	Three varieties	45.1	55.6	13.1	0.9	11.9	.469	54.5	490	98	97	97
Check plots, not top-dressed		1086	Michikof	38.6	57.3	13.2	....	12.5	.499	58.1	562	98	97	97
Check plots, not top-dressed	None	1082	Fulhio	54.6	56.6	12.1	....	10.6	.447	53.0	480	98	98	98
Check plots, not top-dressed		1078	American Banner	48.9	56.2	11.1	....	9.4	.418	52.9	510	98	97	98
Av. not top-dressed plots	....	Av.	Three varieties	47.4	56.7	12.1	....	10.8	.455	54.7	517	98	97	98
Av. top-dressed Michikof	....	Av.	Three treatments	38.2	56.4	14.4	1.2	13.6	.527	57.6	581	99	99	98
Av. top-dressed Fulhio	....	Av.	Three treatments	53.7	56.4	13.2	1.1	11.8	.443	53.6	481	97	97	97
Av. top-dressed American Banner	....	Av.	Three treatments	49.2	55.7	11.8	0.7	10.3	.436	53.9	458	96	96	97

*All plots received basic treatment of 320 pounds 2-14-4 fertilizer at seeding time.
†Increase in percentage wheat protein due to treatment.

TABLE 24.—Effect of Top-dressing Fulhio with Various Treatments at Wooster, 1931

Fertilizer applied*	Nitrogen applied	Sample	Yield per acre	Test weight	Wheat protein	Increase†	Flour protein	Flour ash	Absorption	Loaf volume	Grain	Texture	Color score
	Lb.	*No.*	*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Cc.*			
Nitrate of soda, at heading	97.50	1068	50.4	57.1	14.0	2.9	12.6	0.436	55.1	460	97	95	96
Nitrate of soda, at heading	48.75	1067	48.8	57.5	13.5	1.4	12.3	.464	54.4	502	98	98	97
Nitrate of soda, at heading	32.50	1066	49.7	57.5	13.0	0.9	11.7	.451	55.1	495	97	97	96
Nitrate of soda, at heading	16.25	1065	51.1	57.4	12.4	0.3	11.3	.462	52.7	500	98	98	97
Nitrate of soda, Apr. 15, and again at heading	16.25	1069	48.9	56.5	12.9	0.8	11.6	.466	53.2	445	98	95	96
Nitrate of soda, April 15	97.50	1057	41.2	54.2	14.2	2.1	12.9	.487	55.3	455	98	96	94
Nitrate of soda, April 15	48.75	1056	46.0	55.8	13.2	1.1	12.0	.435	56.0	450	95	96	95
Nitrate of soda, April 15	32.50	1055	46.9	56.3	12.9	0.8	11.7	.430	54.6	505	99	97	95
Nitrate of soda, April 15	16.25	1054	50.9	57.1	12.6	0.5	11.1	.449	56.3	505	97	98	96
Sulfate of ammonia, April 15	97.50	1071	43.3	54.3	14.1	2.0	12.9	.482	53.1	420	96	96	95
Sulfate of ammonia, April 15	32.50	1070	47.4	56.2	12.8	0.7	11.7	.463	54.0	505	97	96	96
Calnitro, April 15	32.50	1073	48.2	56.4	13.2	1.1	11.8	.448	53.8	495	98	98	98
Nitrophoska (15-30-15), April 15	32.50	1064	42.2	56.0	13.2	1.1	11.6	.435	54.7	455	96	97	97
Ammophos B (16-20-0), April 15	32.50	1063	42.9	55.1	13.1	1.0	11.6	.461	54.9	505	99	98	96
Urea, April 15	32.50	1072	49.1	56.9	13.1	1.0	11.7	.447	54.2	475	97	97	97
Ammophos A (11-48-0), April 15	32.50	1062	39.9	54.5	13.0	0.9	11.6	.470	56.7	492	97	97	96
Nitrate of soda, March 15	32.50	1058	47.7	57.0	12.9	0.8	11.7	.488	55.7	467	98	97	95
Nitrate of soda, Nov. 1, 1930	32.50	1059	50.2	57.1	13.0	0.9	11.3	.463	54.0	505	96	96	95
Nitrate of soda, at seeding	97.50	1074	47.8	56.7	13.3	1.2	11.8	.444	53.3	505	97	97	97
Average check, not top-dressed	....	....	50.8	57.9	12.1	....	10.8	.428	55.8	514	98	98	96
Average No. 1065-1068, nitrated at heading	....	....	50.0	57.4	13.2	1.4	12.0	.453	54.3	489	98	97	97
Average No. 1054-1057, nitrated April 15	....	....	46.3	55.9	13.2	1.1	11.9	.450	55.6	479	97	97	95

*All plots received basic application of 320 pounds 2-14-4 fertilizer at seeding time.
†Increase in percentage wheat protein due to treatment.

TABLE 25.—Effect of Amount and Kind of Nitrogen Carrier Applied as Top-dressing on Trumbull at Wooster, 1933

Fertilizer applied*	Nitrogen applied	Sample	Yield per acre	Test weight	Wheat protein	Increase†	Flour protein	Flour ash	Absorption	Loaf volume	Grain	Texture	Color score
	Lb.	*No.*	*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Cc.*			
Nitrate of soda, April 15	97.50	2199	46.2	58.8	13.4	3.5	11.9	0.45	57.6	580	99	99	99
Nitrate of soda, April 15	48.75	2198	44.5	59.4	11.5	1.6	9.8	.40	54.5	600	99	99	99
Nitrate of soda, April 15	32.50	2197	41.7	60.0	10.5	0.6	9.0	.43	55.6	555	100	100	99
Nitrate of soda, April 15	16.25	2196	42.5	59.3	10.3	0.4	8.7	.43	56.6	557	101	100	99
Sulfate of ammonia, April 15	97.50	2203	46.1	57.8	13.1	3.2	11.3	.41	55.8	632	100	99	99
Sulfate of ammonia, April 15	48.75	2202	43.7	59.3	10.9	1.0	9.3	.41	55.2	590	101	100	100
Sulfate of ammonia, April 15	32.50	2201	42.4	59.6	10.7	0.8	8.9	.37	55.8	585	100	100	99
Sulfate of ammonia, April 15	16.25	2200	37.0	59.8	10.0	0.1	8.7	.41	55.6	550	97	100	98
Calnitro, April 15	32.50	2204	41.9	59.6	10.5	0.6	9.2	.40	55.4	590	98	98	99
Not top-dressed	Check	2195	35.5	60.0	9.9	....	8.2	.39	56.9	580	99	99	99
Av. nitrate of soda plots (2196–2199)	....	....	43.7	59.4	11.4	1.5	9.9	.43	56.1	573	100	100	99
Av. sulfate of ammonia plots (2200–2203)	....	....	42.3	59.1	11.2	1.3	9.6	.40	55.6	589	100	100	99

*All plots received a uniform basic treatment of 320 pounds 2-14-4 fertilizer at seeding time.
†Increase in wheat protein over check, due to treatment.

Again in 1933 the nitrogen carriers influenced protein production. On the average, nitrogen from sulfate of ammonia for the third successive year proved less effective for producing protein than nitrogen from nitrate of soda. From a protein standpoint, however, this is an advantage for the sulfate of ammonia, as it is desirable that Ohio soft red winter wheats have only a medium amount of protein. In seasons such as 1934, any practice which increases protein to any extent is undesirable from the millers' viewpoint. However, the use of top-dressing with nitrogen fertilizers will not be particularly detrimental to the quality of the wheat marketed in normal seasons.

EFFECT OF FERTILIZERS APPLIED AT SEEDING TIME

In the section dealing with the influence of soils upon the quality of the wheat grown, it was pointed out that the fertility of the soil had a definite influence upon the strength of wheat. The available nutrient supplies in the soil may be the result of supplies occurring naturally or they may consist partly of nutrients from added fertilizers or manures. It is through these added fertilizers that some possibility exists for the control of the quality of wheat grown in Ohio. It has already been shown that top-dressing may alter the protein content of the resulting crop. Most of these top-dressing tests had to do with nitrogen applications. Crop yields on Ohio soils are usually improved by applications of phosphate and, to a lesser extent, by potash fertilizers in addition to nitrogen. Applications of phosphate and potash are normally made at seeding time.

Information regarding the influence of these fertilizer treatments has been obtained at various times for many years at Wooster from the 5-year rotation started in 1894. In the present investigation, as many of the earlier data as were available from various sources have been added to those obtained more recently by the author. Many of the data to be presented formed the basis of an earlier publication (16) but, being a part of the quality studies commenced in 1929, are included herewith. Only a very abbreviated description of the field treatments used in the experiment will be included, as they have already been outlined in detail by Thorne (44).

The 5-year Rotation Experiment consists of 150 one-tenth acre plots, divided into five tracts or "sections" of land (A, B, C, D, and E), each section containing 30 plots. Twenty of these 30 plots receive either chemical fertilizers or manure. All crops and treatments are represented every year.[4] The soil, derived from glaciated sandstone and shale material, is Wooster silt loam which is naturally deficient in both phosphates and lime (44). The land was underdrained in 1893. Due to clover failures it was decided to lime half of each plot; accordingly, commencing in 1900, the corn crop has received lime at a rate equivalent to 2 tons of ground limestone per acre. Originally, only the west ends of the plots were supposed to receive lime; however, the east ends of Sections E, B, and A received applications in 1905, 1906, and 1907, respectively. Beyond these single applications, however, no lime has been applied to the east ends of the plots.

In the present study only 12 treatments are represented. The fertilizer treatments given these particular plots at the present time are presented in Table 26. During the earlier years part of the nitrogen, now supplied as nitrate of soda, was carried as dried blood.

It has already been stated that the 5-year rotation was started in 1894. Since that time a great deal of work has been done on the material resulting from this experiment. In the present case, the author has gone through the records and collected protein and other desired data. In this work he has been

[4]Sections A, B, and E discontinued after 1933.

privileged to have access to many of the original records of several associates on the Station Staff, particularly those of J. W. Ames and L. E. Thatcher. Some of these data have already been published and these publications have been referred to extensively. However, in the case of protein data it was necessary to convert all figures to a uniform basis by multiplying the nitrogen content by the factor 5.7. No corrections have been made for moisture, but the 1923-1924-1925 data by Hunt (31) as given herein have been calculated to a moisture-free basis whereas the 1931-1932 data obtained by the author are given on a 15 per cent moisture basis. This variation in moisture basis makes the data unsuitable for studying the annual effect of climate upon the protein content. Data antedating those of Hunt have largely been obtained from publications by Ames and co-workers (2, 3, 4). Data for the year 1906, hitherto unpublished, were obtained from the original records of Mr. Ames. The data for test weight per bushel were compiled from original sources.

TABLE 26.—Fertilizer Treatments for Certain 5-year Rotation Plots

(Fertilizer materials in pounds per acre*)

Plot No.	On corn			On oats			On wheat		
	P	K	N	P	K	N	P	K	N
2	128	....	....	128	....	....	128	....	....
3	....	80	....	....	80	....	....	80	....
4	....	....	....	....	....	....	....	....	....
5	....	....	160	....	....	160	....	....	160
6	128	....	160	128	....	160	128	....	160
8	128	80	....	128	80	....	128	80	....
9	....	80	160	....	80	160	....	80	160
11	128	80	160	128	80	160	128	80	160
17	128	80	80	128	80	80	128	80	80
18	8 tons yard manure			....	....	....	8 tons yard manure		
21†	256	80	80	256	80	80	256	80	80
23‡	256	40	80	256	40	80	256	40	80

*P as 20 per cent superphosphate, K as muriate of potash, N as nitrate of soda.

†Previous to 1921, each grain crop received the N in oil meal and only one-half as much superphosphate.

‡Previous to 1921, each grain crop received only one-half as much superphosphate, twice as much muriate of potash, and N in dried blood.

Previous to 1925, Plots 2, 6, 8, and 11 received only 64 pounds of superphosphate on corn and oats.

Previous to 1925, Plots 3, 8, 9, 11, 17, and 21 received 100 pounds of muriate of potash on wheat, instead of 80 pounds.

Baking data from the earlier years are limited. Baking data for the 1931, 1932, and 1933 crop samples from the plots listed in Table 26 have been given by the author elsewhere (15). On account of the paucity of baking data, for the purpose of this study the quality of the wheat grown under the several treatments will be considered in two ways: (1) strength of the crop, represented by crude protein in the wheat, and (2) milling quality, represented by the test weight per bushel. That the crude protein of soft winter wheat is positively and significantly correlated with strength measured by baking tests has been shown by Zinn (47), Bayfield and Shiple (17), and Bayfield (9, 10, 13). That test weight per bushel is related to milling quality measured in terms of yield of flour has been shown by a number of investigators, several of whom are cited by Bailey (8). Heavy wheats normally produce more flour per bushel milled than light-weight samples.

THE EFFECT OF FERTILIZER TREATMENT ON PROTEIN CONTENT

Table 27 gives the protein contents for the crops harvested from the entire plot. The various treatments have been arranged so that the average protein content increases toward the lower part of the table.

TABLE 27.—Percentage Protein from Selected Plots from 5-year Rotation
(Average result for limed and unlimed ends)

Plot No.	Treatment applied to wheat crop	1902	1904	1905	1906	1907	1908	1910	1911	1916	1923	1924	1925	1931	1932	4-year av.†	7-year av.‡
23	2 P ½K ½N	9.3	10.2	....	9.9	9.2	8.9	....	....	....	....	....	....	....	9.6	9.40	9.52§
21	2 P K ½N	9.2	10.4	11.3	9.7	9.7	8.7	....	....	....	....	....	....	....	9.9	9.50	9.84
8	P K	9.7	10.5	10.8	9.4	10.1	9.1	....	....	....	....	....	....	....	10.4	9.75	10.00
17	P K ½N....................	10.0	....	10.8	10.2	10.2	8.8	....	....	....	11.5	11.8	12.2	....	10.1	9.82	10.02§
2	P	11.2	12.2	10.7	10.4	10.3	8.7	....	....	....	12.7	12.8	11.7	....	10.4	9.95	10.56
18	Manure....................	11.4	11.6	11.4	10.4	10.7	9.3	....	....	....	....	....	....	....	11.3	10.42	10.87
11	P K N......................	11.2	11.1	11.7	10.8	10.6	10.2	....	....	....	12.7	12.7	12.0	....	10.8	10.60	10.91
6	P N	11.9	12.1	12.2	11.0	11.0	9.9	....	....	....	....	....	....	....	11.2	10.77	11.33
4	Nothing....................	12.9*	11.9*	13.4*	12.5	11.3	10.0	....	....	....	14.5	12.2	12.5	....	12.6	11.60	12.08
3	K	13.3	12.4	13.9	12.8	10.8	10.0	....	....	....	14.3	12.1	12.2	....	13.0	11.65	12.31
9	K N	14.3	12.0	14.7	13.2	12.3	11.4	....	....	....	11.2	13.2	....	....	12.7	12.40	12.94
5	N	14.4	12.2	14.8	13.7	12.6	11.4	....	....	....	15.6	13.1	12.7	....	13.6	12.82	13.24

*Average of all unfertilized plots.
†Average for the years 1906, 1907, 1908, and 1932.
‡Average for the years 1902, 1904, 1905, 1906, 1907, 1908, and 1932.
§6-year average only.

The question arises as to whether there is any significant difference between the protein contents resulting from the various soil treatments. It will be observed that results are available from comparable pairs of plots for a varying number of years; thus, for example, there are 6 years in which Treatments 23 and 21 produce comparable pairs. Odds against the occurrence of a difference as great as that existing between such pairs by chance alone may be computed readily by Student's method (42). Such odds were calculated for a number of pairs of treatments. The table of odds prepared by Love (35) was used in these calculations. Table 28 gives the odds for significant difference for certain pairs of treatments.

TABLE 28.—Odds That the First Plot Given is Producing a Lower Protein Wheat Than the Second Plot

Plots compared	Number of years represented	Odds favoring first plot
23 and 21	6	2.8 : 1
21 and 8	7	3.6 : 1
8 and 17	6	2.4 : 1
17 and 2	9	14.5 : 1
2 and 18	7	11.7 : 1
18 and 11	7	Less than 1.1 : 1
11 and 6	7	27.1 : 1
6 and 4	7	77.1 : 1
4 and 3	10	3.9 : 1
3 and 9	9	2.4 : 1
9 and 5	9	10.5 : 1
23 and 5	6	3332.0 : 1
2 and 5	10	4999.0 : 1

Table 28 indicates that significant differences in protein content occur between plots which are receiving treatments differing rather widely in nutrient make-up—e. g., Plots 23 and 5. Treatments adjacent to each other in Table 27, however, in most cases do not differ in protein content significantly. These insignificant odds, however, do show a definite tendency in all cases for higher protein wheats to come from any treatment which is located in the table below the treatment with which it is being compared. Table 27, therefore, indicates trends in the relative effect of fertilizer treatments upon the protein content of wheat produced under these several treatments.

From a consideration of the single element treatments it is seen that phosphorus (P) is the most effective element for the production of low-protein wheat, potassium (K) is less effective, and nitrogen (N) produces the greatest percentage of protein. In the two-element treatments it is again found that P and N act in opposite directions. In the three-element treatments the same general trends are noticeable—the more P the less protein. The action of K is less apparent. Plot 23 receiving a one-half rate of K seems to be an exception, but it will be recalled that this plot received as much K as did Plot 21 until the year 1921, when changes in fertilizer treatment were made.

THE EFFECT OF LIMING ON PROTEIN CONTENT

Beginning with the 1906 wheat crop, the east (no lime) and west (limed) ends have been harvested separately. Table 29 gives the protein contents which have been determined up to the present time. As in Table 27 the treatments have been arranged in the general order of increasing amount of protein from the top to the bottom of the table. It should be observed that the order of the treatments is the same in Tables 27 and 29, with the exception of Plots 3 and 4 which are reversed in the case of the west ends.

TABLE 29.—Protein Content, in Per Cent, for Wheat from Limed and Unlimed Ends of Plots

Plot No.	Treatment applied to wheat	1902	1904	1905	1906	1907	1908	1910	1911	1916	1923	1924	1925	1931	1932	4-year av.†
	East ends—unlimed															
23	2 P ½K ½N	......	......	......	9.9	9.1	8.6	......	......	......	......	......	......	......	9.3	9.22
21	2 P K ½N	......	......	......	9.7	9.2	8.7	......	......	......	......	......	......	9.7	9.6	9.30
8	P K	......	......	......	9.6	10.1	8.7	......	......	......	......	......	......	9.9	10.4	9.70
17	P K ½N	......	......	......	10.4	10.1	8.4	......	......	......	11.3	12.0	12.1	10.7	9.9	9.70
2	P	......	......	......	10.6	10.2	8.6	......	......	......	12.5	12.9	11.7	10.2	10.4	9.95
18	Manure	......	......	......	10.5	10.6	9.1	......	......	......	......	......	......	11.4	11.3	10.37
11	P K N	......	......	......	10.5	10.4	10.3	......	......	......	12.9	12.4	12.3	12.1	11.0	10.55
6	P N	......	......	......	11.2	10.8	9.7	......	......	......	......	......	......	12.8	11.1	10.70
4	None	......	......	......	13.4	10.8	9.6	......	......	......	14.4	12.1	12.1	14.3	12.0	11.45
3	K	......	......	......	13.4	10.5	9.7	......	......	......	14.2	11.8	12.1	14.7	12.7	11.57
9	K N	......	......	......	13.5	11.6	11.1	......	......	......	11.3	13.3	......	15.3	12.9	12.27
5	N	......	......	......	14.1	11.8	10.7	......	......	......	15.8	12.7	11.6	15.1	13.4	12.50
	West ends—limed															
23	2 P ½K ½N	......	......	......	10.0	9.4	9.1	......	......	9.9	......	......	......	......	10.0	9.62
21	2 P K ½N	......	......	......	9.7	10.2	8.7	......	......	......	......	......	......	......	10.3	9.72
8	P K	......	......	......	9.2	10.1	9.6	10.9	12.7	10.3	......	......	......	......	10.5	9.85
17	P K ½N	......	......	......	10.0	10.2	9.2	......	......	10.4	11.8	11.7	12.4	......	10.4	9.95
2	P	......	......	......	10.1	10.5	8.8	11.4	12.9	9.9	13.0	12.8	11.8	......	10.5	9.97
18	Manure	......	......	......	10.4	10.8	9.6	10.4	12.8	10.5	......	......	......	......	11.3	10.52
11	P K N	......	......	......	11.2	10.8	10.1	12.6	13.9	10.8	12.6	13.1	11.8	......	10.7	10.70
6	P N	......	......	......	10.8	11.2	10.0	12.7	14.2	11.1	......	......	......	......	11.3	10.82
3	K	......	......	......	12.1	11.2	10.3	13.4	14.8	......	14.4	12.5	12.3	......	13.3	11.72
4	None	......	......	......	11.7	11.8	10.5	......	15.0*	......	14.6	12.4	13.0	......	13.3	11.82
9	K N	......	......	......	12.9	13.0	11.7	14.5	15.5	12.4	11.2	13.2	......	......	12.5	12.52
5	N	......	......	......	13.2	13.3	12.1	14.4	17.3	12.2	15.4	13.6	13.8	......	13.8	13.10

*Average for all unfertilized plots.
†Average for years 1906, 1907, 1908, and 1932.

It can be seen in Table 29 that analyses are available from both ends of the plots for all plots concerned for the years 1906, 1907, 1908, and 1932. Odds have been calculated for these 4 years for the limed (west) ends compared with the unlimed (east) ends with the following results:

Year	Odds	In favor of being higher on
1906	63 : 1	unlimed ends
1907	1110 : 1	limed ends
1908	1666 : 1	limed ends
1932	48 : 1	limed ends
4-year average	15 : 1	limed ends

Examination of the data in Table 29 for other years for which the data are not complete shows a decided tendency for liming to increase the protein content. Why, therefore, should the year 1906 show results just the reverse? A possible and reasonable explanation appears to lie in the treatment given the soil. Section D, which produced this crop, differed in 1906 from the other sections in that it alone grew wheat on land which had not previously produced a crop of limed clover on the west end. There would, therefore, have been relatively less organic matter actively decaying on this section in 1906 than there would have been if a heavier clover crop had preceded the wheat earlier in the rotation. In addition, the action of lime upon the availability of soil phosphorus must be considered. Ames and Schollenberger (5) working with Wooster silt loam soil found that liming produced more available phosphorus which could be measured by the amount assimilated by the wheat plant. Russell (38) states that liming acid soils increases the solubility of phosphates. Recently, Salter and Barnes (39) have shown that grain yields on Wooster silt loam soil may be maintained for long periods without the application of phosphatic fertilizers, provided the pH of the soil is increased by liming to somewhat over 7.0. The improved yielding ability of this soil was due to increased availability of phosphorus, as the acidity of the soil was lessened by liming. We have already seen that phosphorus fertilizer produces lower protein wheat. Accordingly, the west ends in 1906, as a result of the action of the lime, probably had more phosphorus available than did the east ends, with a consequent reduction in protein content. In other years this tendency would be offset by the additional nitrates resulting from a vigorous growth of clover on the limed ends.

EFFECT OF FERTILIZER TREATMENT ON TEST WEIGHT PER BUSHEL

For this study the test weight records were comparatively complete for the same series of years for which protein data are available. Since the data for the year 1910 were incomplete, they are not included. Data for the year 1923 from Plot 23 are also missing. Table 30 gives the average test weight per bushel for the 10 years for which test weights from each end of the plots are available. In addition, 13-year averages for the entire plots are given. These averages include the above 10 years plus the years 1902, 1904, and 1905. The treatments are presented in order of increasing protein content.

TABLE 30.—Average Test Weight (Pounds) per Bushel

Plot No.	Treatment applied on wheat	10-year average			13-year average
		Unlimed ends	Limed ends	Entire plot	Entire plot
		Lb. per bu.	*Lb. per bu.*	*Lb. per bu.*	*Lb. per bu.*
23*	2 P ½K ½N	59.68^{2}†	59.17^{4}	59.39^{2}	58.93^{3}
21	2 P K ½N	59.42^{3}	59.07^{5}	59.22^{5}	58.59^{8}
8	P K	59.36^{4}	59.40^{3}	59.37^{3}	59.34^{2}
17	P K ½N	59.20^{7}	59.45^{2}	59.30^{4}	58.86^{4}
2	P	58.90^{9}	58.71^{6}	58.80^{7}	58.61^{6}
18	Manure	59.99^{1}	59.52^{1}	59.72^{1}	59.38^{1}
11	P K N	59.35^{5}	58.49^{7}	58.88^{6}	58.75^{5}
6	P N	59.33^{6}	58.00^{8}	58.64^{8}	58.61^{6}
4	None	58.15^{11}	56.91^{12}	57.50^{11}	57.15^{11}
3	K	58.58^{10}	57.89^{9}	58.21^{10}	57.65^{10}
9	K N	59.15^{8}	57.84^{10}	58.47^{9}	57.84^{9}
5	N	57.74^{12}	57.03^{11}	57.36^{12}	56.66^{12}

*9- and 12-year averages, respectively.
†The small prime numbers refer to the relative ranking in order of decreasing test weight.

Examination of the relative ranking of the various test weights resulting from the different treatments shows that the expected decrease in test weight with increasing protein content holds in a general way only. The manured plot (Plot 18) is the one most consistently out of line, and this treatment produced the heaviest wheat throughout. Hall (28) gives data from the Broadbalk Field at Rothamsted, England, showing a similar beneficial effect of barnyard manure upon the test weight. The unmanured plot in the Broadbalk Field produced relatively heavier wheat than the no-treatment plot (Plot 4) at Wooster. At Wooster this plot ordinarily produces many shriveled grains. This condition is accentuated by the additional nitrogen resulting from the increased growth of clover on the limed end of the plot.

Available nitrogen, particularly when not balanced by enough phosphorus and potassium, produces the greatest decrease in test weight. Potash applied alone produced heavier wheat than nitrogen alone. Phosphate alone, however, has given heavier wheat than the other two elements, whether supplied singly or in combination. In the case of the two-element treatments, it is seen that the PK (Plot 8) treatment is superior to the PN (Plot 6) or KN (Plot 9) treatments. However, the PK treatment is superior to P alone. With the three-element or complete treatments, the double amounts of phosphorus given to Plots 21 and 23 are producing heavier wheat than Plot 11 (PKN). Plot 17 (PK½N) apparently receives a nutrient supply that is very sensitive to other factors as its relative ranking is variable. It is commonly considered that potash fertilizers produce heavier test weight wheat. This belief is corroborated by the data given by Hall (28) and also by the data in the present study. The relative behavior of Plot 23 (2P½K½N), when compared with Plot 21 (2PK½N), seems to contradict this. However, it will be recalled that these two plots received the same amounts of muriate of potash previous to 1921. Sufficient data are not available to bring out any expected differences at this time.

EFFECT OF LIME UPON TEST WEIGHT PER BUSHEL

From Table 30 it may be seen that the east ends (no lime) are producing heavier wheat than are the limed west ends. Thatcher (43), working with a different series of plots in the 5-year rotation and with a different series of years from that used in this study, found a considerable annual variation in test weight response to liming. Liming in some seasons produced significant decreases in test weight whereas the reverse held true in other seasons. Odds favored the unlimed ends (for heavier test weight) of fertilized plots more often than the limed ends. Similar calculations of odds by Student's method (42) for the different years in this study were made in order to see whether the differences due to liming were significant. These results are presented in Table 31.

TABLE 31.—A Comparison of Test Weight per Bushel by Years

Year	Average of 12 treatments, no lime	Average of 12 treatments, limed	Odds favoring unlimed ends being higher	Odds favoring limed ends being higher	Wheat grown on sections
	Lb.	*Lb.*			
1906	57.9	57.4	3 : 1	....	D
1907	61.0	60.5	39 : 1	....	E
1908	60.2	60.1	13 : 1	....	B
1911	58.4	59.5	....	114 : 1	D
1916	60.4	60 9	....	58 : 1	D
1923	58.5	58.4	27 : 1	....	B
1924	59.7	57.7	over 9999 : 1	....	A
1925	60.3	58.5	over 9999 : 1	....	C
1931	56.9	54.5	over 9999 : 1	....	D
1932	57.2	57.0	5 : 1	....	E

From Table 31 it is readily seen that in this experiment liming produces a lower test weight in a majority of years. It does not seem reasonable to assume that this decrease in test weight is due entirely to the increase in protein content resulting from the addition of lime to the west ends, although the factors causing this protein difference no doubt enter into the problem. There is, undoubtedly, more nitrogen available and this would tend to reduce the test weight by disturbing the balance in nutrient supplies. Due to much heavier yields of crops, the relative amounts of P and K would be less on the west (limed) ends although liming does increase the availability of the soil phosphates. The action of lime upon the availability of the soil potassium probably is also a factor. Potassium is recognized as being essential to photosynthesis and the elaboration of carbohydrate material (Gortner, 27). Ames and Simon (6) found that the addition of calcium oxide to Wooster silt loam soil decreased the amount of water-soluble potassium in the soil and a number of recent investigators cited by Russell (38) show that lime protects the soil potassium against leaching losses. In other words, lime does not aid in supplying available potassium to the plant. Recently, McCalla (36) has demonstrated with wheat grown in water culture that an abundant supply of potassium in the nutrient solution increases the weight per thousand kernels and the quality of gluten. It may be, therefore, that there is insufficient available potassium on the limed ends to take care of the larger yields being produced, with a consequent lower test weight per bushel. A correctly balanced supply is needed if maximum yields are to be combined with high test weight and high protein content.

THE EFFECT OF SOIL REACTION UPON WHEAT QUALITY

Soils throughout Ohio and the Tri-State Territory are very frequently acid in reaction. The degree of acidity (pH) varies in different sections and in different soils. Of the Ohio soils it has already been said that the lacustrine soils of Northwestern Ohio are less acid than the other large soil areas in the State. These lacustrine soils are frequently neutral (pH 7.0) or slightly alkaline at the surface. On the other hand, the Clermont soil (Illinoian Drift) in the southern part of Ohio and Indiana is acid to a depth of several feet (in some cases as deep as 12 feet).

In considering the influence of fertilizers upon the protein content of wheat, it has been pointed out that lime increases the availability of phosphorus and decreases the availability of potassium in the Wooster silt loam soil at Wooster. This soil naturally is acid in reaction with a pH of somewhat above 5.0. In view of the facts that only that part of the nutrient supply in the soil which is available influences the crop and that the reaction of the soil influences the availability of the nutrient supply, soil reaction thus becomes important as a possible factor influencing crop quality.

A series of wheat samples, suitable for a study of the influence of soil reaction upon wheat quality, became available in 1929 and again in 1932 from the "Legume-reaction Experiment" at Wooster. Details of this experiment have been given by Salter and Barnes (39). Briefly, the experiment consists of a 3-year rotation—corn, small grain (wheat, oats, and barley alternating), and hay. Seven different hay crops (six different legumes and one non-legume, timothy) are grown each year. (The wheat samples were composites obtained from all seven plots planted to these different hays for harvest the year following.)

The three ranges comprising the experimental area were crossed by treatments to vary the reaction of the soil, which was slightly above pH 5.0 in 1926 when the experiment was laid down. It was intended to have these cross treatments produce five different reactions with pH values of approximately 4.5, 5.0, 6.0, 7.0, and 8.0 (the average actual reaction has equaled pH 4.7, 5.2, 5.9, 6.8, and 7.4). These approach the original intended figures fairly closely, with the exception of the most alkaline plot (pH 7.4) which is still considerably less alkaline than intended (pH 8.0). Acidity in the cross-treated sections was increased by applying sulfur or aluminum sulfate; whereas the reaction was made more alkaline by additions of pulverized limestone.

The Canfield silt loam soil was naturally rather low in fertility. The fertilizer treatments called for no manure or nitrogenous fertilizer whatsoever, the applications being 40 pounds of muriate of potash on corn and 50 pounds of muriate of potash on small grain. In addition, superphosphate (20 per cent) was applied to half of each plot, the rate being 200 pounds (broadcast) on corn and 400 pounds on small grains. Thus, soil reactions, as well as phosphate fertilizer, are influencing the wheat grown in the experiment. Unfortunately, the two crops of wheat which have been available for study offer too few data for the drawing of definite conclusions. The data presented in Table 32 do, however, permit some speculation. Due to the large differences in yield in the 2 years and also to changes in baking procedures, the individual results for both years are given.

Considering the averages for all reactions in each year, it is apparent that the non-phosphated sections are producing lower test weight and higher protein wheat than the sections receiving phosphate. The baking results are inconclusive insofar as quality of gluten is concerned. In eight out of the 10 possible non-phosphated versus phosphated comparisons, the non-phosphated sections gave wheat with the larger loaves. The differences in size of loaf, indicating strength, very probably were due to the increases in amount of protein in the non-phosphated samples and not to variations in gluten quality.

TABLE 32.—Effect of Soil Reaction Upon Quality of Trumbull Wheat

Intended soil reaction	Not phosphated (north end)				Phosphated (south end)			
	Yield per acre	Test weight	Wheat protein	Loaf volume	Yield per acre	Test weight	Wheat protein	Loaf volume
pH	Bu.	Lb.	Pct.	Cc.	Bu.	Lb.	Pct.	Cc.
				1929 crop				
4.5	12.6	55.3	11.2	1690	35.7	59.0	11.1	1640
5.0	13.8	54.3	11.2	1640	40.3	58.2	10.1	1620
6.0	17.9	54.8	11.4	1650	39.4	58.2	9.1	1550
7.0	24.9	56.3	10.4	1530	41.3	59.2	9.2	1610
8.0	30.4	57.9	10.1	1520	46.6	58.8	9.8	1630
Average	19.9	55.7	10.9	1606	40.7	58.7	9.9	1610
				1932 crop				
4.5	7.0	57.9	11.7	577	16.8	59.5	10.6	552
5.0	8.8	58.2	11.0	580	18.4	60.0	9.9	515
6.0	13.4	58.3	11.2	615	29.1	60.0	9.9	520
7.0	20.5	57.6	11.6	605	35.2	60.3	10.6	512
8.0	25.2	59.5	10.8	560	29.4	60.2	10.5	472
Average	15.0	58.3	11.3	587	25.8	60.0	10.3	514

Considering the effect of soil reaction upon test weight, it is observed that the increase in pH (due to added lime) on the non-phosphated sections is producing increases in test weight. These results contradict those obtained in the 5-year rotation where liming decreased the test weight. Data in Table 30 show a tendency for test weight to increase with added P. Available P may therefore be a major factor governing test weight of wheat grown on the "Legume-reaction Experiment". It may be expected that available P will increase with increasing pH on the non-phosphated sections. On the phosphated sections, however, plenty of available P is present at the lowest pH, due to the treatment, and very little variation in test weight is noticeable among reactions.

The crude protein figures are interesting and serve as an example of the possible complexities in the problem of soil nutrient supplies, yield per acre, and wheat strength. While there undoubtedly are many factors interacting to produce the protein results obtained, the principal factors probably are available supplies of phosphorus and nitrogen in the soil. These two factors, as already pointed out, act in opposite directions insofar as protein production is concerned. The phosphated section has the larger amount of available P (39) and produces one per cent less protein on the average for all reactions. These wheats show decreasing percentages of protein from pH 4.5 to 6.0; then the percentage tends to increase. Nitrogen supplies for these plots must come largely from the legume hay crop residues and the yields of these hay crops rise sharply above pH values of 6.0. Above this figure, therefore, the increasing amounts of nitrogen very probably offset the action of the large supplies of available P. Below pH 6.0 the N from the crop residues plus that of the soil is sufficient to produce satisfactory yields but is below the amount needed to produce high-protein content of the grain.

The non-phosphated plots tend to show decreasing percentages of wheat protein as the soil becomes more alkaline; with this increase in pH the available P also increases (39). Legume growth is similarly stimulated but to a less extent than on the phosphated ends. The extra yields from the higher reactions probably use up these additional supplies of N, so that the higher reaction plots do not show any tendency toward increasing protein content. Increasing N supply on the non-phosphated plots does not, therefore, mask the influence of increasing supplies of available P. While the above may not prove to be the eventual explanation, it is now offered as a possible one.

SUMMARY AND CONCLUSIONS

The effect of several environmental factors influencing the quality of soft winter wheat during the 5-year period, 1929-1933, has been discussed under the various sections in this publication. This comprises the report, in part, of wheat quality studies carried out by the Ohio Agricultural Experiment Station, in cooperation with the Tri-State Soft Winter Wheat Improvement Association, the Ohio State University, Purdue University, and Michigan State College. The cooperative project was undertaken with the object of eliminating undesirable varieties and of fostering desirable varieties in the various sections of the three states so that maximum benefit will accrue to the three interests concerned—grower, miller, and the consuming public.

Climate was found to exert the largest influence upon wheat strength and quality. The effect of climate was studied indirectly by winter wheat abandonment acreage figures and directly from 5-day averages for mean daily temperatures and precipitation during the 50-day period preceding harvesting. Areas of heavy abandonment were found to produce stronger wheat than sections with less winter injury. Acreage abandoned was associated with soil areas. Temperature apparently acted only as a modifying factor upon precipitation, for, during the 50-day period studied, it produced much less effect than rainfall. Rainfall was found to influence the amount of protein in wheat when it occurred during a 10- to 15-day interval during and just preceding the heading period. Precipitation at this time was associated with a decrease in protein. Climate, of course, can not be controlled by man; however, its effect may be modified somewhat by agricultural practices, such as those changing the heat- or water-absorbing or retaining properties of the soil.

Soil was found to exert almost as much influence upon wheat protein content as climate and was used as a basis for zoning the Tri-State Area for wheat strength. Heavy soil texture was found to be associated with increased percentages of wheat protein. It also appears as though a wider annual range in protein may be expected from heavy soil areas than from sections with medium-textured soils. Color of soil gives a general idea of a soil's probable fertility, and it was observed that darker and more fertile soils gave increased amounts of protein.

Soil origin and age were also considered in the outlining of the zonation program since it was observed that soils derived from limestone produced wheat tending toward a higher protein content than soils derived from noncalcareous sandstone and shale. Very old soils are less fertile than younger soils (geologically speaking) and may be expected to give low-protein wheat, excepting when the yields are low or when the test weight is abnormal. In considering the residual soil areas it should be remembered that the surface is constantly being changed through erosion and, therefore, these soils will be younger than they appear.

The supply of soil nutrients available for the plant is probably the most important soil factor regulating the amount of protein. This supply is, of course, influenced by climate and by type and texture of soil. Both the total amount and the composition of this nutrient supply influence the quantity and quality of protein and, in turn, are affected by soil type and by soil texture, as well as by fertilizer practices and climate. In fact, many agricultural practices influence nutrient supply and make the problem extremely complicated. A proper "balance" between the various elements in the nutrient supply is needed for the desired quality of grain.

Some of the treatments used in the fertilizer studies produced wheats which illustrated how poorly balanced fertilizer applications would produce wheat of undesirable strength or poor test weight. Of the three fertilizer elements investigated, nitrogen increased protein content, phosphorus had the opposite effect, and potassium did not give as clear-cut results, being intermediate between nitrogen and phosphorus in effect.

Test weight per bushel was increased by phosphate fertilizers in both the 5-year Rotation Experiment and the Legume-reaction Experiment. Lime in the 5-year rotation decreased test weight 8 out of 10 years but increased it in the 2 years of the Legume-reaction Experiment. Test weight may increase with either increasing or decreasing protein content; the former occurs when normal well-filled kernels have increasing amounts of protein materials stored between the starch granules and the latter when carbohydrate synthesis is interfered with and the percentage of crude protein becomes progressively greater as the kernels become more and more shrunken.

Soil reaction also affects wheat strength through its effect upon the composition of the nutrient supply; for instance, in passing from an acid to an alkaline reaction the soil potash becomes less available whereas the supply of phosphates becomes more available. Undoubtedly, the other elements in the soil are also influenced and produce their effect upon the crop—some beneficially and others harmfully.

Variety of wheat and yield per acre have been included incidentally in the study because they influence the quality of crop as received by the mills. The quality, as well as quantity, of protein differs with variety. By taking advantage of these characteristics, the strength of wheat in a given area may be altered through the use of the proper variety; thus, low-protein varieties should be grown in sections which naturally tend to produce wheat with too high a protein content.

It is through the use of varieties of suitable strength characteristics and through the use of fertilizer treatments and farm practices giving a suitable nutrient supply that the greatest promise exists for regulating the strength of the wheat reaching the trade.

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TABLE 33.—Protein Content of Wheat, 1930 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	Fulton, Ohio	10.8	9.5	10.4	11.0	9.1	9.6	9.8	10.1	10.4	...	10.08[9]*
2	Fulton, Ohio	9.5	8.4	9.7	9.6	8.1	9.0	8.9	9.0	8.9	...	9.01[9]
3	Fulton, Ohio	9.6	8.5	9.3	9.3	8.4	9.5	9.5	8.9	9.2	...	9.13[9]
4	Fulton, Ohio	10.6	9.4	10.5	9.7	8.9	10.3	10.7	9.9	10.1	...	10.01[9]
5	Fulton, Ohio	...	...	...	...	Winterkilled 100%		...	...	...	...	...
6	Henry, Ohio	...	...	...	...	No planting		...	...	...	...	...
7	Trumbull, Ohio	11.2	10.0	11.4	11.8	9.6	10.6	10.3	9.7	10.0	...	10.51[9]
8	Mahoning, Ohio	10.1	9.3	10.0	10.1	8.5	9.8	9.4	10.0	9.8	...	9.67[9]
9	Wayne, Ohio	10.5	10.2	10.2	10.5	9.2	11.2	10.7	10.8	10.6	...	10.43[9]
10	Knox, Ohio	10.8	10.3	10.9	10.9	9.8	10.8	11.1	11.0	10.9	...	10.72[9]
11	Franklin, Ohio	11.5	10.9	11.1	12.1	10.5	12.5	11.8	11.3	10.8	...	11.39[9]
12	Miami, Ohio	11.8	10.8	11.7	12.1	10.5	11.3	10.7	10.7	10.7	...	11.14[9]
13	Hamilton, Ohio	9.4	8.7	9.1	9.3	9.0	9.4	9.5	8.8	8.9	...	9.12[9]
14	Meigs, Ohio	11.2	9.1	9.5	10.4	10.0	10.5	10.6	10.1	10.2	...	10.18[9]
15	Belmont, Ohio	...	...	...	...	Winterkilled		...	...	...	...	...
16	Jennings, Ind.	13.0	12.4	12.9	13.0	12.4	12.5	11.4	12.5	13.0	...	12.57[9]
17	Lawrence, Ind.	9.9	8.5	9.5	9.2	8.7	9.4	9.9	9.7	9.3	...	9.34[9]
18	Tippecanoe, Ind.	10.2	9.8	9.9	10.1	9.3	10.4	9.8	9.9	9.8	...	9.91[9]
19	Kalamazoo, Mich.	11.6	11.1	11.0	11.6	11.3	12.7	12.0	...	11.5	...	11.60[8]
20	Ingham, Mich.	12.0	10.8	11.7	11.2	11.1	11.9	11.2	...	...	...	11.41[7]
21	Missaukee, Mich.	10.2	8.7	9.8	9.9	8.7	10.0	9.4	...	8.9	...	9.45[8]
22	Branch, Mich.	10.3	9.5	10.3	10.3	9.7	10.3	10.3	...	10.2	...	10.11[8]
23	Branch, Mich.	10.2	9.3	10.3	10.5	9.5	10.3	10.0	...	10.5	...	10.07[8]
24	Ingham, Mich.	10.3	...	10.8	10.6	9.5	10.7	...	...	10.4	...	10.38[6]
25	Clinton, Mich.	...	...	...	...	...	...	...	...	...	...	...
26	Ionia, Mich.	...	...	...	...	...	...	...	...	...	...	...
27	Monroe, Mich.	...	...	...	...	...	...	...	...	...	...	...
28	Sanilac, Mich.	...	...	...	...	...	...	...	...	...	...	...
29	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
30	Lenawee, Mich.	...	...	...	...	...	...	...	...	...	...	...
	Average	10.70	9.76	10.48	10.63	9.66	10.60	10.35	10.16	10.20	...	10.29

*Prime numbers refer to number of varieties averaged where fewer than complete set of 10 varieties were grown.

TABLE 34.—Protein Content of Wheat, 1931 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	Fulton, Ohio	9.3	8.4	9.3	9.3	8.3	8.5	8.6	8.8	9.3	8.4	8.82
2	Fulton, Ohio	9.6	8.6	9.2	9.1	9.1	8.7	9.3	9.5	9.4	8.5	9.10
3	Fulton, Ohio	9.7	8.9	9.5	9.3	8.9	8.9	9.2	8.9	9.0	8.6	9.09
4	Fulton, Ohio	10.8	9.8	10.5	10.1	9.3	10.4	11.0	10.3	9.7	9.1	10.10
5	Fulton, Ohio	9.9	9.6	10.3	9.7	9.8	10.3	10.5	10.3	9.9	9.4	9.97
6	Henry, Ohio	10.5	9.5	9.8	9.5	9.4	9.9	9.9	9.9	9.8	9.2	9.74
7	Trumbull, Ohio	…	…	…	…	…	…	…	…	…	…	…
8	Mahoning, Ohio	10.3	9.4	10.1	9.8	9.6	10.3	10.4	10.0	10.2	9.4	9.95
9	Wayne, Ohio	10.1	9.3	10.2	9.9	8.9	10.1	10.6	10.3	9.7	9.5	9.86
10	Knox, Ohio	10.1	9.4	10.4	9.6	9.0	9.6	10.2	9.7	10.2	9.2	9.74
11	Franklin, Ohio	10.9	10.3	11.2	11.3	9.7	10.2	10.7	11.3	10.7	10.8	10.71
12	Miami, Ohio	11.2	9.9	10.3	11.4	11.4	12.5	12.1	11.1	10.9	10.8	11.16
13	Hamilton, Ohio	12.9	11.3	13.8	13.8	11.3	12.8	13.3	13.3	13.0	11.9	12.74
14	Meigs, Ohio	12.6	11.7	13.3	12.9	10.9	12.5	12.4	11.6	12.1	11.2	12.12
15	Belmont, Ohio	10.0	9.0	9.3	10.0	9.9	10.0	9.7	9.7	9.2	8.7	9.55
16	Jennings, Ind.	9.4	9.3	9.4	9.4	8.6	9.6	9.4	8.9	9.4	9.0	9.24
17	Lawrence, Ind.	10.0	8.5	9.8	9.6	8.4	9.6	9.7	9.8	9.2	9.2	9.38
18	Tippecanoe, Ind.	8.8	8.1	9.0	8.5	8.2	8.8	8.8	9.2	8.6	8.0	8.60
19	Kalamazoo, Mich.	11.0	9.9	10.2	11.1	10.7	11.6	11.6	11.4	10.9	9.9	10.83
20	Ingham, Mich.	11.1	9.7	11.2	10.3	10.5	11.1	9.9	10.1	9.7	9.7	10.33
21	Missaukee, Mich.	14.2	13.4	13.9	14.3	13.1	13.7	15.3	15.4	14.8	15.3	14.34
22	Branch, Mich.	…	…	…	…	…	…	…	…	…	…	…
23	Branch, Mich.	…	…	…	…	…	…	…	…	…	…	…
24	Ingham, Mich.	…	…	…	…	…	…	…	…	…	…	…
25	Clinton, Mich.	12.3	11.7	12.2	13.0	12.7	13.3	12.4	12.8	11.6	13.5	12.55
26	Ionia, Mich.	11.9	11.2	11.6	11.1	11.7	12.3	11.9	12.1	11.5	11.6	11.69
27	Monroe, Mich.	9.8	9.5	10.3	9.5	9.2	9.8	10.0	9.9	9.7	9.5	9.72
28	Sanilac, Mich.	…	…	…	…	…	…	…	…	…	…	…
29	Branch, Mich.	…	…	…	…	…	…	…	…	…	…	…
30	Lenawee, Mich.	…	…	…	…	…	…	…	…	…	…	…
	Average	10.71	9.84	10.64	10.54	9.94	10.63	10.73	10.62	10.37	10.02	10.41

TABLE 35.—Protein Content of Wheat, 1932 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	Fulton, Ohio	10.3	9.7	10.1	9.5	9.1	9.2	9.5	9.4	9.5	9.3	9.56
2	Fulton, Ohio	9.6	9.4	9.7	9.3	8.7	9.2	9.0	8.8	9.2	8.5	9.14
3	Fulton, Ohio	9.6	9.5	9.6	9.4	9.0	9.6	10.1	9.6	9.8	9.1	9.53
4	Fulton, Ohio	10.3	9.8	10.2	10.1	9.6	10.0	11.8	10.3	9.8	9.7	10.16
5	Fulton, Ohio	9.5	9.4	9.5	9.1	9.0	9.4	10.6	9.7	9.6	9.2	9.50
6	Henry, Ohio	10.5	10.1	10.4	9.8	9.5	11.1	10.1	10.0	10.3	9.5	10.13
7	Trumbull, Ohio	...	...	...	...	...	...	...	...	...	...	...
8	Mahoning, Ohio	12.7	12.3	12.7	13.1	11.3	13.7	13.6	13.3	12.8	13.0	12.85
9	Wayne, Ohio	12.2	12.1	12.9	12.8	11.4	12.9	13.7	12.8	12.3	12.7	12.58
10	Knox, Ohio	10.9	10.0	10.3	10.5	9.7	10.6	10.6	10.4	10.5	10.3	10.38
11	Franklin, Ohio	13.3	11.7	13.2	12.4	11.3	13.0	13.0	12.5	12.4	12.3	12.51
12	Miami, Ohio	12.3	12.3	12.2	11.5	10.8	12.6	12.6	12.4	12.4	12.1	12.12
13	Hamilton, Ohio	10.3	9.8	10.6	9.8	8.7	9.4	9.5	9.4	9.4	8.9	9.58
14	Meigs, Ohio	10.9	9.6	9.7	9.6	8.8	10.3	10.4	10.2	9.9	9.9	9.93
15	Belmont, Ohio	13.3	13.7	14.5	14.3	12.0	13.6	14.0	13.3	14.3	13.7	13.67
16	Jennings, Ind.	10.5	9.8	10.8	10.4	9.8	10.0	9.5	10.5	9.8	9.6	10.07
17	Lawrence, Ind.	10.4	9.6	10.7	10.2	9.4	10.6	10.7	10.6	10.5	10.1	10.28
18	Tippecanoe, Ind.	9.9	9.3	9.9	9.5	8.6	10.2	9.7	9.4	9.3	8.8	9.46
19	Kalamazoo, Mich.	...	...	...	...	...	...	...	...	...	...	...
20	Ingham, Mich.	10.4	8.9	10.0	9.4	10.5	9.0	10.2	9.7	9.5	8.6	9.62
21	Missaukee, Mich.	9.9	9.2	10.0	9.6	9.1	9.7	9.7	10.3	9.7	9.9	9.71
22	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
23	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
24	Ingham, Mich.	...	...	...	...	...	...	...	...	...	...	...
25	Clinton, Mich.	...	...	...	...	...	...	...	...	...	...	...
26	Ionia, Mich.	...	...	...	...	...	...	...	...	...	...	...
27	Monroe, Mich.	9.7	9.5	10.0	9.5	9.7	10.1	9.7	9.7	9.7	9.4	9.70
28	Sanilac, Mich.	12.0	11.0	11.4	11.7	10.5	10.9	11.9	12.4	11.3	10.4	11.35
29	Branch, Mich.	10.2	9.3	10.2	10.0	9.3	9.6	9.9	9.2	9.8	8.7	9.62
30	Lenawee, Mich.	11.7	11.3	11.7	9.8	10.1	11.0	10.7	10.7	11.4	10.9	10.93
	Average	10.89	10.32	10.88	10.49	9.82	10.68	10.89	10.63	10.57	10.20	10.54

TABLE 36.—Protein Content of Wheat, 1933 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	Fulton, Ohio	9.0	8.6	9.0	8.8	9.0	9.4	8.6	9.8	9.1	8.7	9.00
2	Fulton, Ohio	10.4	9.4	10.4	10.7	10.2	9.9	11.3	10.3	10.0	9.6	10.22
3	Fulton, Ohio	11.0	11.1	11.6	12.3	11.5	12.4	12.0	11.3	11.4	10.9	11.55
4	Fulton, Ohio	12.4	12.5	12.6	13.3	12.3	13.5	12.4	12.5	12.0	12.9	12.64
5	Fulton, Ohio	11.4	10.8	11.6	11.3	11.0	11.7	11.4	12.0	11.2	11.3	11.37
6	Henry, Ohio	14.0	12.8	13.6	13.8	12.8	13.9	14.0	14.3	13.2	13.6	13.60
7	Trumbull, Ohio	...	...	...	...	...	...	...	...	...	...	...
8	Mahoning, Ohio	10.3	10.0	10.5	11.5	...	...	...	...	...	...	...
9	Wayne, Ohio	11.1	10.0	11.5	11.5	10.1	11.5	11.8	11.5	12.0	10.5	11.15
10	Knox, Ohio	10.5	9.6	11.2	10.8	9.6	10.7	10.2	9.9	10.3	9.3	10.21
11	Franklin, Ohio	11.0	9.6	12.1	10.8	10.3	10.7	11.0	11.5	10.0	9.8	10.68
12	Miami, Ohio	11.2	11.5	11.2	10.2	10.8	11.2	11.3	11.6	11.1	11.0	11.11
13	Hamilton, Ohio	10.9	9.2	10.0	9.9	9.5	10.0	9.4	9.2	9.6	8.1	9.58
14	Meigs, Ohio	10.6	9.5	10.8	10.3	9.9	10.9	10.3	9.8	10.9	9.8	10.28
15	Belmont, Ohio	10.8	9.4	10.3	10.4	10.1	10.9	10.1	10.6	10.5	9.3	10.24
16	Jennings, Ind.	11.0	10.0	11.4	10.5	10.3	10.9	10.9	10.4	10.4	10.0	10.58
17	Lawrence, Ind.	11.0	10.0	11.6	10.2	10.0	10.4	10.3	10.0	10.7	10.0	10.42
18	Tippecanoe, Ind.	10.9	9.9	10.9	10.8	10.0	10.7	10.5	10.7	10.4	10.4	10.52
19	Kalamazoo, Mich.	9.6	8.8	9.1	9.0	8.9	9.0	9.3	9.3	8.6	8.8	9.04
20	Ingham, Mich.	11.3	10.3	11.0	11.8	10.1	11.1	12.2	11.0	11.0	10.5	11.03
21	Missaukee, Mich.	11.6	11.4	11.5	12.7	11.2	11.8	11.8	12.4	11.3	11.2	11.69
22	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
23	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
24	Ingham, Mich.	...	...	...	...	...	...	...	...	...	...	...
25	Clinton, Mich.	...	...	...	...	...	...	...	...	...	...	...
26	Ionia, Mich.	...	...	...	...	...	...	...	...	...	...	...
27	Monroe, Mich.	10.6	11.0	11.0	12.8	10.8	12.7	12.1	11.2	10.9	10.3	11.34
28	Sanilac, Mich.	11.6	11.1	10.6	11.4	10.0	10.5	10.7	10.5	10.7	9.9	10.70
29	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
30	Lenawee, Mich.	11.1	10.1	10.7	11.8	10.2	11.5	11.3	11.6	10.7	10.5	10.90
	Average	11.01	10.29	11.05	11.16	10.39	11.15	11.04	10.97	10.73	10.29	10.81

TABLE 37.—Loaf Volume, 1930 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Cc.	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*
1	Fulton, Ohio	1820	1720	1700	1980	1495	1705	1695	1675	1830	...	1735.5^{9}*
2	Fulton, Ohio	1830	1800	1785	1725	1555	1695	1640	1620	1640	...	1698.9^{9}
3	Fulton, Ohio	1730	1615	1660	1760	1525	1620	1610	1605	1695	...	1646.7^{9}
4	Fulton, Ohio	1770	1690	1820	1920	1630	1615	1710	1600	1800	...	1727.8^{9}
5	Fulton, Ohio	...	...	...	...	...	...	...	...	...	...	...
6	Henry, Ohio	...	...	...	...	...	...	...	...	...	...	...
7	Trumbull, Ohio	1815	1725	1830	2110	1690	1695	1705	1580	1815	...	1773.9^{9}
8	Mahoning, Ohio	1810	1655	1835	1890	1640	1795	1665	1815	1715	...	1757.8^{9}
9	Wayne, Ohio	1815	1805	1660	1900	1655	1795	1795	1875	1790	...	1787.8^{9}
10	Knox, Ohio	1850	1750	1780	1995	1525	1800	1795	1775	1925	...	1799.4^{9}
11	Franklin, Ohio	1835	1740	1870	1825	1845	2015	1935	1950	2035	...	1894.4^{9}
12	Miami, Ohio	1900	2005	1945	1955	1875	1715	1785	1760	1915	...	1872.8^{9}
13	Hamilton, Ohio	1680	1550	1710	1725	1550	1535	1665	1645	1700	...	1640.0^{9}
14	Meigs, Ohio	1765	1700	1635	1835	1665	1620	1645	1785	1720	...	1707.8^{9}
15	Belmont, Ohio	...	...	...	...	...	...	...	...	...	...	...
16	Jennings, Ind.	1835	1795	1685	2045	1905	1810	1790	1920	1985	...	1863.3^{9}
17	Lawrence, Ind.	1635	1495	1555	1570	1600	1555	1540	1535	1610	...	1566.1^{9}
18	Tippecanoe, Ind.	1675	1740	1680	1690	1505	1820	1675	1760	1825	...	1707.8^{9}
19	Kalamazoo, Mich.	1820	1715	1675	1970	1685	1850	1690	...	1920	...	1790.6^{8}
20	Ingham, Mich.	1765	1670	1780	1925	1630	1765	1730	...	...	...	1752.1^{7}
21	Missaukee, Mich.	1730	1590	1635	1900	1410	1700	1590	...	1625	...	1647.5^{8}
22	Branch, Mich.	1690	1695	1665	1890	1560	1725	1760	...	1820	...	1725.6^{8}
23	Branch, Mich.	1690	1735	1770	1840	1510	1655	1555	...	1835	...	1698.7^{8}
24	Ingham, Mich.	1635	...	1515	1845	1490	1750	...	...	1800	...	1672.5^{6}
25	Clinton, Mich.	...	...	...	...	...	...	...	...	...	...	...
26	Ionia, Mich.	...	...	...	...	...	...	...	...	...	...	...
27	Monroe, Mich.	...	...	...	...	...	...	...	...	...	...	...
28	Sanilac, Mich.	...	...	...	...	...	...	...	...	...	...	...
29	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
30	Lenawee, Mich.	...	...	...	...	...	...	...	...	...	...	...
	Average	1766.4	1709.5	1723.3	1871.2	1616.4	1725.5	1698.7	1726.7	1800.0	...	1737.9

*Prime numbers refer to number of varieties averaged where less than complete set of 10 varieties were grown.

TABLE 38.—Loaf Volume, 1931 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Cc.	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*
1	Fulton, Ohio................	470	385	430	420	390	405	380	430	440	422	417.2
2	Fulton, Ohio................	417	445	432	442	430	450	435	425	435	417	432.8
3	Fulton, Ohio................	450	440	452	470	427	470	412	450	425	440	443.6
4	Fulton, Ohio................	465	450	495	490	470	440	472	450	420	447	459.9
5	Fulton, Ohio................	425	457	430	462	425	445	445	440	425	445	439.9
6	Henry, Ohio................	440	428	440	430	410	350	380	410	410	425	412.3
7	Trumbull, Ohio............	....	....	....	....	....	....	....	....	....	....	....
8	Mahoning, Ohio............	460	425	445	480	408	450	432	432	435	462	442.9
9	Wayne, Ohio................	430	450	470	462	432	427	457	450	440	425	444.3
10	Knox, Ohio................	442	415	405	420	420	435	440	425	427	387	421.6
11	Franklin, Ohio.............	500	450	510	480	435	420	460	472	472	460	465.9
12	Miami, Ohio................	485	410	435	460	465	452	450	470	450	460	453.7
13	Hamilton, Ohio.............	505	410	503	480	450	465	485	510	455	485	474.8
14	Meigs, Ohio................	455	420	360	400	385	400	410	430	395	437	409.2
15	Belmont, Ohio..............	390	355	387	340	380	417	410	372	410	393	385.4
16	Jennings, Ind...............	450	415	450	450	410	360	440	420	440	435	427.0
17	Lawrence, Ind..............	470	440	462	470	425	467	450	453	460	473	457.0
18	Tippecanoe, Ind............	420	380	445	360	380	415	420	415	410	365	401.0
19	Kalamazoo, Mich...........	477	525	532	520	470	495	480	507	507	502	501.5
20	Ingham, Mich.	535	510	527	520	490	535	512	460	500	530	511.9
21	Missaukee, Mich.	500	485	492	520	422	512	430	465	455	457	473.8
22	Branch, Mich...............	....	....	....	....	....	....	....	....	....	....	....
23	Branch, Mich...............	....	....	....	....	....	....	....	....	....	....	....
24	Ingham, Mich...............	....	....	....	....	....	....	....	....	....	....	....
25	Clinton, Mich...............	497	505	507	535	422	510	490	500	492	495	495.3
26	Ionia, Mich.................	490	515	517	515	417	490	475	500	460	520	489.9
27	Monroe, Mich...............	520	500	475	472	450	450	465	472	450	477	473.1
28	Sanilac, Mich........	....	....	....	....	....	....	....	....	....	....	....
29	Branch, Mich...............	....	....	....	....	....	....	....	....	....	....	....
30	Lenawee, Mich..............	....	....	....	....	....	....	....	....	....	....	....
	Average................	464.9	444.1	460.9	460.8	426.6	446.1	444.8	450.3	444.0	450.4	449.3

TABLE 39.—Loaf Volume, 1932 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.
1	Fulton, Ohio	530	520	555	535	445	505	530	535	530	520	520.5
2	Fulton, Ohio	565	530	547	567	535	505	505	510	510	490	526.4
3	Fulton, Ohio	540	535	540	507	520	535	570	542	542	535	536.6
4	Fulton, Ohio	552	515	530	512	517	520	555	542	520	422	518.5
5	Fulton, Ohio	515	490	535	550	475	467	542	545	542	495	515.6
6	Henry, Ohio	620	610	610	600	522	600	600	600	565	570	589.7
7	Trumbull, Ohio											
8	Mahoning, Ohio	625	590	645	685	612	717	680	605	602	625	638.6
9	Wayne, Ohio	590	552	575	677	562	612	630	580	530	620	592.8
10	Knox, Ohio	580	555	582	592	522	565	560	562	562	565	564.5
11	Franklin, Ohio	640	575	627	630	567	625	637	632	620	610	616.3
12	Miami, Ohio	612	642	615	592	600	682	640	662	635	645	632.5
13	Hamilton, Ohio	622	612	617	572	515	537	520	560	547	505	560.7
14	Meigs, Ohio	585	530	550	547	522	560	575	525	535	567	549.6
15	Belmont, Ohio	562	650	672	707	595	635	680	640	697	655	649.3
16	Jennings, Ind.	575	495	570	540	505	570	520	600	528	568	547.1
17	Lawrence, Ind.	518	505	525	548	470	540	538	538	540	568	529.0
18	Tippecanoe, Ind.	570	525	560	555	498	555	560	515	545	495	537.8
19	Kalamazoo, Mich.											
20	Ingham, Mich.	585	507	577	562	565	560	517	540	537	530	548.0
21	Missaukee, Mich.	510	520	537	557	500	527	527	500	485	595	525.8
22	Branch, Mich.											
23	Branch, Mich.											
24	Ingham, Mich.											
25	Clinton, Mich.											
26	Ionia, Mich.											
27	Monroe, Mich.	547	555	572	565	497	492	482	525	550	515	530.0
28	Sanilac, Mich.	622	592	652	630	530	577	615	620	572	585	599.5
29	Branch, Mich.	545	500	565	575	535	590	535	580	550	560	553.5
30	Lenawee, Mich.	555	515	520	495	462	555	560	537	532	555	528.6
	Average	572.4	548.7	577.3	578.3	524.8	566.6	568.6	565.0	555.5	556.3	561.3

TABLE 40.—Loaf Volume, 1933 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.	Cc.
1	Fulton, Ohio	540	530	532	535	520	557	535	575	552	577	545.3
2	Fulton, Ohio	655	595	632	665	572	585	607	630	602	645	619.1
3	Fulton, Ohio	650	590	637	662	585	652	595	620	670	630	629.1
4	Fulton, Ohio	630	622	640	680	580	672	597	630	577	682	631.0
5	Fulton, Ohio	580	580	610	652	600	617	615	655	610	650	616.9
6	Henry, Ohio	665	605	682	615	610	650	640	627	632	625	635.1
7	Trumbull, Ohio	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	Mahoning, Ohio	625	627	625	640	.....	.....	.....	.....	.....	.....	629.3[4]*
9	Wayne, Ohio	647	575	650	632	537	595	600	630	617	642	612.5
10	Knox, Ohio	610	572	607	575	535	595	570	625	590	587	586.6
11	Franklin, Ohio	605	565	560	610	542	610	590	585	590	615	587.2
12	Miami, Ohio	585	620	585	565	550	580	595	590	570	605	584.5
13	Hamilton, Ohio	527	567	607	595	555	575	550	547	575	530	562.8
14	Meigs, Ohio	630	590	640	640	580	635	600	590	610	610	612.5
15	Belmont, Ohio	575	527	552	620	547	625	565	595	560	577	574.3
16	Jennings, Ind.	630	615	615	622	547	600	620	597	590	580	601.6
17	Lawrence, Ind.	605	602	607	595	542	622	582	620	595	570	594.0
18	Tippecanoe, Ind.	557	595	577	595	517	562	580	600	595	607	578.5
19	Kalamazoo, Mich.	550	547	540	555	515	535	525	540	517	525	534.9
20	Ingham, Mich.	662	655	710	715	590	640	645	640	680	680	661.7
21	Missaukee, Mich.	590	635	605	620	635	590	590	565	602	610	604.2
22	Branch, Mich.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
23	Branch, Mich.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
24	Ingham, Mich.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
25	Clinton, Mich.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
26	Ionia, Mich.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
27	Monroe, Mich.	645	625	615	645	555	597	585	620	620	632	613.9
28	Sanilac, Mich.	633	615	625	660	575	622	610	615	650	600	620.5
29	Branch, Mich.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
30	Lenawee, Mich.	600	570	615	615	550	607	555	572	590	595	586.9
	Average	608.5	592.3	611.6	622.1	560.9	605.6	588.7	603.1	599.7	607.9	600.2

*Prime numbers refer to number of varieties averaged where less than complete set of 10 varieties were grown.

TABLE 41.—Test Weight per Bushel, 1930 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average[9]*
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
1	Fulton, Ohio	62.2	62.0	62.3	62.3	60.3	61.6	61.5	62.2	61.7	...	61.8
2	Fulton, Ohio	60.7	59.1	60.0	59.5	57.5	60.0	61.0	60.7	60.5	...	59.9
3	Fulton, Ohio	60.7	60.1	60.8	60.2	57.9	62.2	60.6	62.0	61.0	...	60.6
4	Fulton, Ohio	61.2	61.6	61.8	61.0	58.3	61.4	61.4	61.5	62.3	...	60.7
5	Fulton, Ohio	...	...	...	...	Winter-killed	...	...	...	...	...	...
6	Henry, Ohio	...	...	...	...	No sowing	...	...	...	...	...	...
7	Trumbull, Ohio	61.9	62.0	61.2	61.2	58.9	59.0	61.2	62.2	60.5	...	60.9
8	Mahoning, Ohio	61.3	61.6	61.1	62.1	59.2	60.8	60.6	62.0	62.5	...	61.2
9	Wayne, Ohio	62.2	62.7	62.0	63.0	60.6	63.0	62.7	63.2	62.2	...	62.4
10	Knox, Ohio	62.7	63.2	62.6	61.6	59.8	61.9	61.6	62.6	62.1	...	62.0
11	Franklin, Ohio	59.7	60.1	60.3	62.0	59.7	59.2	61.0	62.4	60.2	...	60.5
12	Miami, Ohio	60.4	60.5	60.8	60.3	59.4	61.8	61.5	63.4	61.3	...	61.0
13	Hamilton, Ohio	62.5	62.5	62.0	61.3	60.5	62.3	61.4	62.6	61.5	...	61.8
14	Meigs, Ohio	59.7	60.3	59.8	60.2	58.8	62.0	59.7	60.2	59.1	...	60.0
15	Belmont, Ohio	...	...	...	...	No sowing	...	...	...	...	...	...
16	Jennings, Ind.	60.2	61.0	60.9	60.6	59.4	61.8	61.2	61.7	61.6	...	60.9
17	Lawrence, Ind.	61.3	60.8	61.1	59.9	60.3	61.7	61.2	62.8	61.2	...	61.1
18	Tippecanoe, Ind.	60.9	61.5	61.6	61.2	60.9	62.1	61.0	62.2	61.2	...	61.4
19	Kalamazoo, Mich.	62.1	62.2	61.8	61.1	60.6	61.7	61.1	...	61.0	...	61.4[8]*
20	Ingham, Mich.	62.9	63.2	63.2	62.0	61.9	62.6	62.8	...	...	...	62.7[7]
21	Missaukee, Mich.	61.0	61.8	60.7	58.7	60.2	60.7	60.5	...	61.2	...	60.6[8]
22	Branch, Mich.	63.3	63.3	63.3	62.4	61.2	62.6	62.0	...	62.6	...	62.6[8]
23	Branch, Mich.	62.6	63.0	62.6	62.2	60.9	63.1	62.1	...	62.4	...	62.4[8]
24	Ingham, Mich.	60.7	...	61.0	60.4	59.7	61.2	...	...	61.3	...	60.7[6]
25	Clinton, Mich.	...	...	...	...	...	...	...	...	...	...	...
26	Ionia, Mich.	...	...	...	...	...	...	...	...	...	...	...
27	Monroe, Mich.	...	...	...	...	...	...	...	...	...	...	...
28	Sanilac, Mich.	...	...	...	...	...	...	...	...	...	...	...
29	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
30	Lenawee, Mich.	...	...	...	...	...	...	...	...	...	...	...
	Average	61.4	61.6	61.5	61.1	59.8	61.6	61.3	62.1	61.4	...	61.28

*Prime numbers refer to number of varieties averaged where less than complete set of 10 varieties were grown.

TABLE 42.—Test Weight per Bushel, 1931 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
1	Fulton, Ohio	59.4	59.2	59.8	59.5	56.7	59.5	57.5	59.3	59.4	59.1	58.9
2	Fulton, Ohio	60.7	59.8	59.4	59.7	57.9	60.1	59.8	58.0	59.0	59.3	59.4
3	Fulton, Ohio	60.4	59.6	60.8	59.3	57.2	60.3	58.6	59.4	59.0	59.4	59.4
4	Fulton, Ohio	59.7	59.6	60.0	59.5	57.3	60.3	59.9	60.6	60.0	60.5	59.7
5	Fulton, Ohio	59.6	59.1	59.8	60.0	57.4	60.0	59.2	57.7	59.0	59.7	59.1
6	Henry, Ohio	59.7	60.1	59.6	60.5	58.3	61.0	59.3	59.8	59.2	60.3	59.8
7	Trumbull, Ohio	...	...	...	...	...	...	...	...	...	...	...
8	Mahoning, Ohio	60.4	60.8	60.6	60.3	58.6	60.4	59.6	60.4	60.0	60.0	60.1
9	Wayne, Ohio	57.4	57.3	57.2	57.6	55.3	58.2	56.4	56.6	56.4	57.6	57.0
10	Knox, Ohio	57.4	60.1	57.4	58.5	55.7	59.3	58.5	58.6	57.5	58.1	58.1
11	Franklin, Ohio	55.6	57.0	55.5	56.0	55.0	55.2	55.1	57.1	56.3	55.1	55.8
12	Miami, Ohio	55.1	55.0	55.5	54.4	52.0	54.6	54.5	55.0	54.2	55.2	54.5
13	Hamilton, Ohio	54.2	53.0	53.0	52.3	51.6	51.7	52.5	51.2	50.6	54.6	52.5
14	Meigs, Ohio	56.8	55.5	55.0	56.3	55.7	59.0	57.0	57.6	55.1	55.7	56.4
15	Belmont, Ohio	56.7	55.4	57.0	54.8	54.2	56.7	56.6	55.4	55.7	57.5	56.0
16	Jennings, Ind.	57.6	57.9	58.6	57.9	56.0	59.8	57.6	57.2	58.8	57.5	57.9
17	Lawrence, Ind.	57.7	58.1	58.0	58.5	55.8	58.5	57.7	58.5	58.1	57.7	57.9
18	Tippecanoe, Ind.	59.3	58.7	59.8	59.2	57.1	59.6	59.1	58.8	59.7	58.2	58.9
19	Kalamazoo, Mich.	60.0	60.0	60.1	60.1	58.2	60.6	58.6	60.3	59.8	59.8	59.7
20	Ingham, Mich.	60.4	59.9	60.5	60.0	59.0	60.7	59.1	60.2	59.5	59.3	59.9
21	Missaukee, Mich.	58.0	58.0	58.4	57.1	58.4	58.6	58.2	57.6	58.2	57.5	58.0
22	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
23	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
24	Ingham, Mich.	...	...	...	...	...	...	...	...	...	...	...
25	Clinton, Mich.	57.4	58.7	58.1	56.7	56.6	57.8	57.8	57.6	58.0	56.0	57.5
26	Ionia, Mich.	58.4	59.1	58.8	58.5	58.1	59.2	58.5	59.5	59.4	58.0	58.7
27	Monroe, Mich.	58.9	59.4	58.6	59.8	57.8	60.2	59.3	59.4	59.4	59.0	59.2
28	Sanilac, Mich.	...	...	...	...	...	...	...	...	...	...	...
29	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
30	Lenawee, Mich.	...	...	...	...	...	...	...	...	...	...	...
	Average	58.3	58.3	58.3	58.1	56.5	58.7	57.8	58.1	57.9	58.0	58.02

TABLE 43.—Test Weight per Bushel, 1932 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
1	Fulton, Ohio	58.8	60.5	59.1	59.2	56.4	58.0	57.8	57.7	58.4	57.3	58.3
2	Fulton, Ohio	60.3	60.0	60.6	59.2	58.4	59.1	56.7	56.9	58.0	56.6	58.6
3	Fulton, Ohio	61.3	61.6	61.3	61.1	59.0	60.7	59.0	60.4	60.3	60.7	60.5
4	Fulton, Ohio	59.5	59.0	59.6	60.2	57.2	59.7	57.6	59.5	58.5	58.5	58.9
5	Fulton, Ohio	58.8	59.0	58.9	59.0	56.3	59.3	57.3	57.9	58.5	57.3	58.2
6	Henry, Ohio	62.8	62.5	62.8	62.7	61.0	62.5	62.3	62.3	62.2	62.0	62.3
7	Trumbull, Ohio	...	...	...	...	...	...	...	...	...	...	...
8	Mahoning, Ohio	60.1	60.8	59.7	60.2	59.9	60.8	60.4	60.5	60.2	61.1	60.4
9	Wayne, Ohio	61.2	61.2	59.3	60.4	59.4	60.5	59.7	60.9	60.5	60.2	60.3
10	Knox, Ohio	61.3	61.6	61.9	61.7	60.3	61.0	60.5	60.9	61.0	61.2	61.1
11	Franklin, Ohio	60.3	62.0	61.1	61.9	59.5	60.3	60.9	61.6	60.7	61.4	61.0
12	Miami, Ohio	60.1	58.2	60 4	61.1	57.5	60.6	60.9	59.8	60.3	60.8	60.0
13	Hamilton, Ohio	58.8	60.4	59.8	60.0	58.0	59.4	59.6	59.9	59.6	58.9	59.4
14	Meigs, Ohio	59.5	59.2	58.4	57.3	57.9	59.0	59.3	59.2	59.6	58.5	58.8
15	Belmont, Ohio	59.9	60.6	59.5	60.0	60.7	60.8	60.2	60.6	60.5	60.5	60.3
16	Jennings, Ind.	56.7	57.5	57.9	56.1	54.1	56.8	57.4	57.8	57.6	56.6	56.8
17	Lawrence, Ind.	57.0	59.3	57.2	56.2	54.2	58.9	58.7	58.2	58.9	57.2	57.6
18	Tippecanoe, Ind.	61.6	61.7	61.4	60.8	58.7	61.6	60.8	61.4	60.4	60.4	60.9
19	Kalamazoo, Mich.	...	...	...	...	...	...	...	...	...	...	...
20	Ingham, Mich.	59.7	59.1	59.7	58.2	60.0	60.4	59.8	58.5	58.4	58.6	59.2
21	Missaukee, Mich.	60.2	60.7	60.0	60.5	59.1	61.3	60.6	60.8	60.9	61.1	60.5
22	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
23	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
24	Ingham, Mich.	...	...	...	...	...	...	...	...	...	...	...
25	Clinton, Mich.	...	...	...	...	...	...	...	...	...	...	...
26	Ionia, Mich.	...	...	...	...	...	...	...	...	...	...	...
27	Monroe, Mich.	57.4	59.0	57.3	57.8	57.8	60.1	58.7	59.0	58.5	59.0	58.5
28	Sanilac, Mich.	59.3	60.9	59.2	59.1	59.2	59.5	59.7	60.0	59.6	58.4	59.5
29	Branch, Mich.	58.6	58.9	58.3	58.1	57.0	58.0	58.5	58.8	59.3	58.0	58.3
30	Lenawee, Mich.	61.0	61.5	61.2	61.7	60.1	61.5	61.4	61.1	61.2	60.6	61.1
	Average	59.7	60.2	59.8	59.7	58.3	60.0	59.5	59.7	59.7	59.3	59.60

TABLE 44.—Test Weight per Bushel, 1933 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
1	Fulton, Ohio	58.9	60.0	56.9	58.3	55.8	59.2	58.3	60.5	59.2	59.7	58.7
2	Fulton, Ohio	58.7	59.5	59.3	57.6	58.7	59.0	59.2	59.4	59.3	59.4	59.0
3	Fulton, Ohio	59.0	59.5	59.0	59.3	59.1	60.1	59.4	60.5	60.4	60.2	59.7
4	Fulton, Ohio	59.1	59.5	59.1	59.6	58.3	59.5	59.4	60.7	59.9	59.7	59.5
5	Fulton, Ohio	59.4	60.0	59.4	60.0	59.3	60.0	60.1	60.4	59.8	60.4	59.9
6	Henry, Ohio	59.3	59.2	59.8	59.6	59.7	61.0	59.7	60.7	60.7	60.2	60.0
7	Trumbull, Ohio	....	....	....	....	....	....	....	....	....	....	....
8	Mahoning, Ohio	60.3	60.2	60.6	59.1	....	....	....	....	....	....	60.1*
9	Wayne, Ohio	60.0	60.2	60.2	60.5	59.2	60.7	60.2	60.8	60.1	60.7	60.3
10	Knox, Ohio	60.7	61.6	61.2	60.0	59.0	60.0	60.0	60.6	60.1	61.6	60.5
11	Franklin, Ohio	57.7	59.1	56.7	59.4	57.7	58.3	58.6	58.2	58.0	59.2	58.3
12	Miami, Ohio	56.2	57.1	58.6	56.8	56.2	58.7	57.5	57.9	57.3	56.9	57.3
13	Hamilton, Ohio	57.3	57.2	58.1	57.3	55.5	57.4	57.3	57.3	57.9	56.2	57.2
14	Meigs, Ohio	58.3	59.0	58.7	58.8	57.3	59.3	58.3	58.5	59.2	58.8	58.6
15	Belmont, Ohio	58.8	60.0	58.6	59.2	58.5	60.3	59.5	59.4	60.0	59.3	59.4
16	Jennings, Ind.	56.9	58.6	57.5	58.2	56.7	58.6	57.1	58.2	58.6	55.7	57.6
17	Lawrence, Ind.	55.2	57.1	54.8	56.8	53.3	56.1	57.6	56.9	58.4	55.5	56.2
18	Tippecanoe, Ind.	58.5	59.2	58.6	58.0	57.5	59.5	59.1	59.8	58.8	59.1	58.8
19	Kalamazoo, Mich.	61.2	60.6	61.3	59.9	59.3	60.9	60.1	61.5	60.1	60.6	60.5
20	Ingham, Mich.	59.1	60.5	59.0	59.1	58.1	60.7	59.3	59.4	59.2	58.7	59.3
21	Missaukee, Mich.	62.0	61.6	61.6	61.2	60.7	61.2	61.3	62.5	61.7	62.1	61.6
22	Branch, Mich.	....	....	....	....	....	....	....	....	....	....	....
23	Branch, Mich.	....	....	....	....	....	....	....	....	....	....	....
24	Ingham, Mich.	....	....	....	....	....	....	....	....	....	....	....
25	Clinton, Mich.	....	....	....	....	....	....	....	....	....	....	....
26	Ionia, Mich.	....	....	....	....	....	....	....	....	....	....	....
27	Monroe, Mich.	59.9	60.9	59.8	59.2	59.2	61.3	60.3	61.4	61.0	61.2	60.4
28	Sanilac, Mich.	59.0	60.3	58.8	59.4	58.4	60.6	60.0	60.9	60.3	59.9	59.8
29	Branch, Mich.	....	....	....	....	....	....	....	....	....	....	....
30	Lenawee, Mich.	59.8	60.2	60.9	60.4	60.2	61.5	61.0	61.3	61.0	61.3	60.8
	Average	58.9	59.6	59.1	59.0	58.1	59.7	59.2	59.8	59.6	59.4	59.25

*Four varieties only.

TABLE 45.—Yield per Acre, 1930 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Bu.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
1	Fulton, Ohio............	14.3	19.0	15.1	14.5	16.9	15.4	15.2	13.7	12.8	....	15.2
2	Fulton, Ohio............	38.9	42.7	43.5	40.2	42.0	36.9	40.3	31.5	35.4	....	39.0
3	Fulton, Ohio............	27.8	32.8	30.0	28.5	27.3	27.1	29.9	30.6	26.1	....	28.9
4	Fulton, Ohio............	46.1	41.6	43.0	43.9	45.3	42.8	33.5	36.5	40.7	....	41.5
5	Fulton, Ohio............	....	....	....	....	....	Winterkilled	....	....	....	....	....
6	Henry, Ohio	....	....	....	....	....	No sowing	....	....	....	....	....
7	Trumbull, Ohio	29.3	27.3	31.1	24.1	27.0	11.8	16.4	17.3	24.5	....	23.2
8	Mahoning, Ohio	24.2	28.7	26.7	22.7	15.0	15.8	19.8	23.1	24.1	....	22.2
9	Wayne, Ohio	39.8	39.4	40.6	41.0	35.8	37.3	33.5	31.1	36.1	....	37.2
10	Knox, Ohio..............	43.4	44.3	35.3	29.7	31.8	25.1	32.9	26.4	33.3	....	34.1
11	Franklin, Ohio	21.8	23.5	21.8	26.3	15.3	17.5	23.5	22.8	24.0	....	21.8
12	Miami, Ohio............	6.3	12.5	16.3	12.3	17.4	25.3	26.7	27.8	21.5	....	18.4
13	Hamilton, Ohio..........	29.8	34.1	30.9	33.3	23.1	28.7	26.6	18.9	32.7	....	28.7
14	Meigs, Ohio............	32.0	35.9	32.7	32.4	24.8	35.7	35.7	21.0	36.0	....	31.8
15	Belmont, Ohio..........	....	....	....	....	....	Winterkilled	....	....	....	....	....
16	Jennings, Ind...........	18.8	18.3	15.5	19.4	14.1	20.3	19.2	16.6	19.7	....	18.0
17	Lawrence, Ind...........	18.9	18.2	17.1	18.5	13.4	18.3	19.0	11.8	17.1	....	16.9
18	Tippecanoe, Ind.........	26.3	29.9	25.4	24.5	27.7	23.9	29.1	24.1	28.9	....	26.6
19	Kalamazoo, Mich........	26.8	27.7	29.3	26.3	29.8	30.3	30.5	....	28.5	....	28.6[8]*
20	Ingham, Mich...........	37.1	43.9	40.8	38.5	44.8	38.0	39.9	....	....	....	40.4[7]
21	Missaukee, Mich.........	35.9	32.8	31.8	33.1	31.9	31.4	36.8	....	32.0	....	33.2[8]
22	Branch, Mich............	31.6	29.7	32.0	29.4	34.1	33.4	31.0	....	27.5	....	31.1[8]
23	Branch, Mich............	19.0	25.5	22.8	24.1	24.9	22.3	22.2	....	23.5	....	23.0[8]
24	Ingham, Mich.	33.8	....	33.4	35.8	36.0	34.4	....	....	38.6	....	35.3[6]
25	Clinton, Mich............	....	....	....	....	....	....	....	....	....	....	....
26	Ionia, Mich.	....	....	....	....	....	....	....	....	....	....	....
27	Monroe, Mich.	....	....	....	....	....	....	....	....	....	....	....
28	Sanilac, Mich...........	....	....	....	....	....	....	....	....	....	....	....
29	Branch, Mich............	....	....	....	....	....	....	....	....	....	....	....
30	Lenawee, Mich.	....	....	....	....	....	....	....	....	....	....	....
	Average............	28.7	30.4	29.3	28.5	27.5	27.2	28.1	23.5	28.1	....	28.1

*Prime numbers refer to number of varieties averaged where less than complete set of 10 varieties were grown.

TABLE 46.—Yield per Acre, 1931 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Berkeley Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Bu.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
1	Fulton, Ohio	7.8	13.3	13.4	12.6	16.3	17.3	12.5	12.3	12.6	15.7	13.4
2	Fulton, Ohio	24.2	26.8	24.1	27.7	25.4	20.2	21.2	20.0	17.0	22.2	22.9
3	Fulton, Ohio	....	....	....	....	No yields available		....	....	....	....	....
4	Fulton, Ohio	42.4	41.5	41.0	43.7	43.1	40.2	42.1	40.0	31.1	42.3	40.7
5	Fulton, Ohio	40.6	43.1	42.9	43.6	40.0	38.1	40.2	35.9	37.0	40.9	40.2
6	Henry, Ohio	35.4	37.2	33.0	36.5	33.8	35.1	33.8	32.6	30.7	35.9	34.4
7	Trumbull, Ohio	....	....	....	....	....	....	....	....	....	....	....
8	Mahoning, Ohio	39.3	40.0	38.3	39.2	34.2	33.8	33.8	32.7	33.5	35.5	36.0
9	Wayne, Ohio	47.3	45.9	47.4	50.2	50.8	40.9	37.6	42.1	42.7	48.0	45.3
10	Knox, Ohio	27.8	33.8	31.1	36.2	35.9	31.4	33.1	32.1	32.0	31.0	32.4
11	Franklin, Ohio	41.3	38.1	39.9	40.2	36.5	41.1	35.2	30.9	35.4	36.4	37.5
12	Miami, Ohio	34.1	30.4	33.5	34.1	25.6	27.3	26.3	33.1	26.0	32.1	30.2
13	Hamilton, Ohio	....	....	....	....	Lodged	....	....	....	....	....	....
14	Meigs, Ohio	47.0	32.7	38.5	41.0	37.7	37.5	35.0	39.1	39.7	49.5	39.8
15	Belmont, Ohio	29.2	29.7	31.2	33.3	26.7	33.0	29.8	30.7	31.7	35.8	31.1
16	Jennings, Ind.	18.6	20.2	19.3	21.5	17.2	22.9	20.2	17.5	23.9	15.1	19.6
17	Lawrence, Ind.	40.7	40.3	40.3	37.3	35.0	36.9	38.7	39.7	39.1	41.1	38.9
18	Tippecanoe, Ind.	43.0	45.2	43.8	47.5	45.5	39.7	41.9	40.8	38.4	45.9	43.2
19	Kalamazoo, Mich.	28.7	31.5	27.9	28.1	25.0	22.4	....	23.8	34.0	....	27.7[8]*
20	Ingham, Mich.	37.2	34.4	39.8	37.4	32.4	35.7	31.5	36.8	33.5	40.4	35.9
21	Missaukee, Mich.	32.3	33.4	36.3	27.1	35.4	29.0	27.6	32.6	28.7	28.2	31.1
22	Branch, Mich.	....	....	....	....	....	....	....	....	....	....	....
23	Branch, Mich.	....	....	....	....	....	....	....	....	....	....	....
24	Ingham, Mich.	....	....	....	....	....	....	....	....	....	....	....
25	Clinton, Mich.	38.2	36.7	32.9	36.4	35.0	33.8	33.4	31.5	30.1	30.0	33.8
26	Ionia, Mich.	18.9	18.9	19.3	20.7	17.8	20.4	20.2	21.4	16.3	23.4	19.7
27	Monroe, Mich.	34.2	36.6	32.6	34.7	30.6	31.7	29.8	29.1	29.4	33.7	32.2
28	Sanilac, Mich.	....	....	....	....	....	....	....	....	....	....	....
29	Branch, Mich.	....	....	....	....	....	....	....	....	....	....	....
30	Lenawee, Mich.	....	....	....	....	....	....	....	....	....	....	....
	Average	33.7	33.8	33.6	34.7	32.4	31.8	31.2	31.2	30.6	34.1	32.7

†Prime numbers refer to number of varieties averaged where less than complete set of 10 varieties were grown.

TABLE 47.—Yield per Acre, 1932 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Bu.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
1	Fulton, Ohio	12.0	11.3	11.3	9.5	10.1	9.8	10.3	12.3	12.5	10.3	10.9
2	Fulton, Ohio	35.4	39.4	36.1	36.9	41.9	31.3	31.8	32.9	31.6	34.6	35.2
3	Fulton, Ohio	37.1	29.6	37.6	33.8	41.1	36.6	37.9	33.9	30.9	36.4	35.5
4	Fulton, Ohio	31.8	32.6	36.1	37.6	32.9	38.7	29.8	32.9	29.1	34.3	33.6
5	Fulton, Ohio	23.9	27.4	25.8	30.4	31.9	33.3	24.9	27.3	24.6	30.8	28.0
6	Henry, Ohio	31.7	29.6	27.8	36.5	33.9	31.7	34.3	33.4	30.0	34.1	32.3
7	Trumbull, Ohio	....	....	....	....	....	....	....	....	....	....	....
8	Mahoning, Ohio	28 3	30.6	28.7	33.2	33.0	33 7	26.8	26.3	28.6	26.2	29.5
9	Wayne, Ohio	21.4	25.9	22 8	30.5	29.3	28.7	26.7	22.4	22.9	25.8	25.6
10	Knox, Ohio	29.1	28.3	28.6	26.4	36.2	28.9	26.8	27.6	26.1	28.3	28.6
11	Franklin, Ohio	17.2	21.2	17.5	23.5	24.4	19.9	19.0	18.2	17.8	18.1	19.7
12	Miami, Ohio	40.4	39.5	41.8	41.8	40.4	39.5	41.3	35.9	36.3	35.0	39.2
13	Hamilton, Ohio	25.1	28.6	28.7	31.2	30.3	30.7	28.7	28.1	27.7	27.7	28.7
14	Meigs, Ohio	29.2	32.2	29.4	22.9	21.7	28.5	24.0	29.2	24.4	23.2	26.5
15	Belmont, Ohio	24.0	22.7	25.7	19.0	21.7	22.7	21.3	21.0	19.7	22.3	22.0
16	Jennings, Ind.	16.6	18.4	....	14.3	12.7	15.5	16.4	14.5	16.4	13.1	15.3[9]*
17	Lawrence, Ind.	19.5	23.4	20.8	16.3	12.9	18.5	21.4	17.5	22.5	17.3	19.0
18	Tippecanoe, Ind.	28.7	30.9	27.5	30.3	31.1	27.7	28.5	28.6	28.5	29.7	29.1
19	Kalamazoo, Mich.	....	....	....	....	....	....	....	....	....	....	....
20	Ingham, Mich.	42.2	43.6	45.5	47.4	44.1	45.5	42.3	42.0	38.4	40.0	43.1
21	Missaukee, Mich.	36.7	36.5	35.0	29.3	32.6	30.3	19.4	34.0	35.9	43.6	33.3
22	Branch, Mich.	....	....	....	....	....	....	....	....	....	....	....
23	Branch, Mich.	....	....	....	....	....	....	....	....	....	....	....
24	Ingham, Mich.	....	....	....	....	....	....	....	....	....	....	....
25	Clinton, Mich.	....	....	....	....	....	....	....	....	....	....	....
26	Ionia, Mich.	....	....	....	....	....	....	....	....	....	....	....
27	Monroe, Mich.	41.2	37.1	37.8	36.6	35.9	35.8	37.0	37.1	39.8	43.3	38.2
28	Sanilac, Mich.	26.8	29.8	26.1	25.5	32.2	28.5	30.6	28.0	22.5	30.6	28.1
29	Branch, Mich.	26.6	21.9	20.1	27.8	36.1	35.3	26.5	32.8	30.5	38.1	29.6
30	Lenawee, Mich.	57.4	53.8	58.3	60.0	57.2	57.3	47.0	35.2	47.7	43.9	51.8
	Average	29.7	30.2	30.4	30.5	31.5	30.8	28.4	28.3	28.0	29.9	29.7

*Prime numbers refer to number of varieties averaged where less than complete set of 10 varieties were grown.

TABLE 48.—Yield per Acre, 1933 Crop

No.	Location, County	Variety										
		Trumbull	Nabob	Fulhio	Red Rock	American Banner	Bald Rock	Michigan Amber	Kharkov	Fultz	Gladden	Average
		Bu.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
1	Fulton, Ohio	17.1	23.9	23.8	18.7	21.6	19.7	16.2	21.9	20.0	21.3	20.4
2	Fulton, Ohio	28.4	29.4	27.5	23.3	25.8	24.5	21.9	20.4	25.3	21.7	24.8
3	Fulton, Ohio	27.3	26.5	24.3	20.3	20.8	18.2	23.0	22.2	19.9	26.7	22.9
4	Fulton, Ohio	31.6	34.1	35.2	25.1	27.1	24.6	29.6	30.8	30.5	31.6	30.0
5	Fulton, Ohio	28.6	29.9	29.0	24.6	25.3	22.1	25.4	25.3	27.6	28.7	26.7
6	Henry, Ohio	...	...	...	...	No yields available		...	...	...	...	27.5*
7	Trumbull, Ohio	...	...	...	...	...	...	...	...	...	...	...
8	Mahoning, Ohio	36.5	36.3	39.9	31.7	Samples lost		...	...	...	...	36.1[4]†
9	Wayne, Ohio	51.5	48.0	48.7	41.1	41.0	41.6	38.5	45.7	42.5	49.7	44.8
10	Knox, Ohio	36.5	36.2	34.2	26.4	28.3	25.9	27.7	33.4	31.7	37.7	31.8
11	Franklin, Ohio	29.1	34.1	29.3	31.4	28.0	27.5	29.2	28.8	29.8	32.1	29.9
12	Miami, Ohio	41.7	46.7	41.7	36.3	37.2	40.4	38.6	41.7	38.6	43.1	40.6
13	Hamilton, Ohio	39.8	37.6	38.5	34.1	33.7	35.6	33.7	38.9	34.6	29.3	36.6
14	Meigs, Ohio	35.6	38.9	31.9	27.3	25.5	29.0	22.7	30.2	25.8	32.7	30.0
15	Belmont, Ohio	25.4	27.3	27.7	19.6	22.1	24.6	24.6	28.1	26.7	23.5	25.0
16	Jennings, Ind.	15.3	15.8	...	16.7	13.1	13.3	15.9	16.8	16.1	15.1	13.8[9]
17	Lawrence, Ind.	23.2	23.7	21.7	27.2	18.8	24.6	22.8	23.1	21.4	24.6	23.1
18	Tippecanoe, Ind.	33.4	33.1	33.9	32.0	34.0	36.4	30.8	34.3	28.6	33.5	33.0
19	Kalamazoo, Mich.	25.4	27.5	27.1	24.8	22.5	23.4	21.8	22.6	24.3	23.0	24.2
20	Ingham, Mich.	29.0	31.2	28.5	29.8	25.1	27.4	28.1	28.7	25.5	28.6	28.2
21	Missaukee, Mich.	27.9	28.3	27.0	21.6	27.1	28.9	31.5	29.2	27.2	22.4	27.1
22	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
23	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
24	Ingham, Mich.	...	...	...	...	...	...	...	...	...	...	...
25	Clinton, Mich.	...	...	...	...	...	...	...	...	...	...	...
26	Ionia, Mich.	...	...	...	...	...	...	...	...	...	...	...
27	Monroe, Mich.	23.7	24.4	24.9	27.0	23.8	27.6	28.6	23.0	24.7	18.6	24.6
28	Sanilac, Mich.	29.3	25.1	30.9	25.7	25.6	25.2	25.3	27.2	...	24.6	26.5[9]
29	Branch, Mich.	...	...	...	...	...	...	...	...	...	...	...
30	Lenawee, Mich.	33.4	30.6	30.0	30.4	29.7	26.6	32.9	27.1	27.5	29.9	29.8
	Average	30.4	31.3	31.2	27.0	26.5	27.0	27.1	28.5	27.4	28.5	28.5

*Estimated.
†Prime numbers refer to number of varieties averaged where less than complete set of 10 varieties were grown.

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